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A. B. CONNER, DIRECTOR
COLLEGE STATION, BRAZOS COUNTY, TEXAS

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DIVISION OF RURAL HOME RESEARCH

The Effect of Sunlight and Other Factors On the Strength and Color of Cotton Fabrics

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
T. O. WALTON, President

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*Dean, School of Veterinary Medicine.
**In cooperation with U. S. Department of Agriculture.
‡In cooperation with Texas Extension Service.
†As of February 1, 1933.
††On leave.

Cotton is by far the most important agricultural commodity in Texas and a complete knowledge of its qualities and characteristics is necessary to insure its best utilization. Previous work of the Texas Experiment Station has dealt largely with the culture of the crop, the control of diseases and insect pests, and the economic considerations involved in marketing the product. Some important work also has been done in the utilization of the seed as a feed or fertilizer. The present bulletin presents the results of the first of a series of investigations of the cotton fiber as an industrial product, and deals with the effects of sunlight, temperature, and relative humidity on the strength and color of cotton fabrics differing in structure, color, and dye. It was found that length of time of exposure to sunlight is the most important factor in the deterioration of cotton fabrics, temperature and relative humidity having slight effect. The various fabrics were significantly different in losses of strength following exposure, those with coarse, hard twisted yarns losing less strength than those with fine, soft twisted yarns. Mercerized fabrics were less weakened than unmercerized. Bleached fabrics lost more in strength than unbleached. Fabrics dyed with vat dyes were less weakened than those dyed with direct dyes. Fabrics also varied in their change in color. In general, guaranteed fabrics were found to be more fast than non-guaranteed and dark colors more permanent than light colors. No one color, however, can be said to be more fast to sunlight than another, the fastness depending on the particular dye when used alone or in combination with other dyes.

Ultra-violet radiation, known to be an important constituent of sunlight, was found to be greater at College Station than at Chicago, Honolulu, or San Juan. Hence fading and loss in strength are probably greater in this region than elsewhere.

These results suggest to the consumer the importance of avoiding unnecessary exposure to sunlight of cotton fabrics, whether white or colored, and the desirability of purchasing materials guaranteed to be color fast. They suggest to the manufacturer producing fabrics for regions having sunlight rich in ultra-violet radiation, the necessity of using only the more permanent dyes. They suggest to the farmer the possibility of producing a more valuable product by reducing the period of exposure in the field, a point now under investigation.

CONTENTS

BULLETIN NO. 474 FEBRUARY, 1933

THE EFFECT OF SUNLIGHT AND OTHER FACTORS ON THE STRENGTH AND COLOR OF COTTON FABRICS

Mary Anna Grimes

Cotton, by far the most important agricultural commodity in Texas and throughout the South, has been the subject of numerous investigations. The many experiments carried on by the Texas Experiment Station, since its first inception, have dealt largely with the production and marketing of the fiber but not with it in the form in which it is utilized by the consumer. The value of the fiber is dependent upon its successful utilization and research dealing with this phase is as important to the farmer as studies in methods of production, control of diseases and pests, and marketing. The findings are of value to the farmer as well as to the manufacturer and consumer.

The present study was undertaken to determine the effect of some of the factors influencing the usefulness of cotton. It has long been known that exposure to the weather caused fabrics to become weakened and frequently to change color. The nature and extent of these changes and the factors producing them have received comparatively little attention particularly in the United States. The investigations in this Bulletin deal primarily with the effects of sunlight, temperature, and relative humidity on cotton fabrics which differ in structure, in color, and in dye. Although much of the discussion is necessarily technical, an effort has been made to point out the immediate practical application of the experimental findings for the producer, manufacturer, and consumer.

THEORIES CONCERNING CAUSES OF FADING AND TENDERING

Factors Influencing Fading by Light

The factors which influence fading occur in the atmosphere surrounding the fabrics and in the fabrics themselves.

Quality of Light. In the literature dealing with fading and tensile strength is found disagreement as to the wave lengths of the spectrum causing the changes in color and strength. Those writing about 1928 (1) and 1929 stressed the importance of ultra-violet light in producing these changes while later articles state that the importance of these wave lengths has been exaggerated, and the effects of the visible rays underestimated. All recent writers agree, however, that ultra-violet rays do play a part in the fading of certain dyes and affect the tensile strength of cotton.

The quantity and quality of light occurring under natural atmospheric conditions are influenced by the geographical location, altitude, season of the year, relative humidity, clouds, and the presence of dust, smoke, and other impurities.

The sub-committee on light fastness of the research committee, American Association of Textile Chemists and Colorists, has probably done more than any other group in the United States in determining the wave lengths of light causing fading (4). They exposed dyeings without covers and with covers of various glasses which transmitted selected parts of the spectrum. From their study they concluded that window glass would be a satisfactory cover for the standard sun test. The wave lengths below 320 millimicrons, which are not transmitted by this glass, are variable in sunlight.

This sub-committee's conclusions may be summarized as follows: some dyes are faded principally by visible radiant energy, some only by visible radiation, some by the regions of both visible and ultra-violet radiation.

The quantity of radiant energy received during exposure, as measured by a photo-electric cell, did not correspond to the amount of fading. The committee attributes this fact to environmental influences, particularly humidity.

Relative Humidity. It has been known for many years that most dyes fade more in moist than in dry atmosphere. Some dyes are more sensitive to moisture than others and will fade more in early spring when the moisture is greater than in dry summer (18). In general, an increase in relative humidity increases fading.

Temperature. There is disagreement of opinions concerning the importance of the part temperature plays in fading. Appel (3) stated in 1928 that "temperature may have an effect but probably it is not a large one and evidence is lacking." In 1931 Cady (14) says both humidity and temperature are important factors. Cunliffe (18) says in 1932 that recent work "has shown that it has a considerable effect. It appears probable that the earlier workers failed to keep up the relative humidity of the atmosphere surrounding the patterns, so that the tendency to produce more fading by a rise in temperature was counterbalanced by the tendency to fade less in a drier atmosphere. As an indication of the importance of this effect, it is found that at the low humidity of 30%, many colors on wool fade 1½ times faster at 60°C than at 25°C, while at saturation the factor is anything from 2 to 5 times." Barker (6) believes that temperature has small effect on dyes which are photo-electric, such as analine dyes, and that the photo-electric effect is probably directly proportional to the amount of ultra-violet wave lengths absorbed.

Atmospheric Impurities. The presence of gases, smoke, dust, and other impurities in the air may retard or accelerate fading, by eliminating light or by contributing to the formation of substances which may act as bleaching agents or as catalysts (14) (18).

The Nature of the Fiber. A given dye is not equally fast on different kinds of fibers. This is to be expected since the fading is a chemical reaction and the fiber may become tendered by the light, resulting in a substance reacting differently in respect to the dye and light (5) (14) (18).

Nature of the Dye. Various workers have noted that the rate of fading is not the same with all dyes. Some fade rapidly at first and then slowly, while others behave in the opposite manner. Some fade slowly in poor light and more rapidly in increased light (14) (18). Some become darker and others lighter; some first darken and then lighten. Wuth (54) believes that the finer the division of the dyestuff, the more the reflection surfaces are decreased; therefore the tendency to fading is decreased.

Cady (14) states that direct dyes on cotton fade by being reduced while most dyes fade by being oxidized. Certain direct dyes will fade on cotton in vacuo when exposed to light. The light partially converts the cellulose into oxycellulose and this oxidation causes the dye to be correspondingly reduced. Most other dyes behave in an opposite manner. They fade in air and not in vacuo, as they require oxygen for fading. The fastness of a dye may be modified by the presence of another dye in combination with it. Two fast dyes are not necessarily fast when combined (5) (18).

Depth of the Dyeing. The fastness of a given dye depends upon the depth of the dyeing. The darker shades fade less rapidly than the lighter and frequently darken before fading (14) (18).

Finishes. Finishes may either increase or decrease the fastness of the dyeing. Some finishing agents, such as castor or cocoanut oil, and corn and olive oil, to a less degree, increase fading (14). The presence of finishes may afford mechanical protection to the dye by coating the fibers so that the light waves which cause fading are excluded. Dextrin, glucose, and stearic acid retard fading. Mercerized cotton when dyed has been found to be more fast to light than unmercerized.

Factors Influencing Tendering by Light

The loss in strength of cotton upon exposure to light and other agencies is caused by the oxidation of the cellulose to form oxycellulose and related degradation products. The oxidizing agents may be present in the fiber itself, the dye, finish, or the atmosphere. The process producing loss in strength is called tendering and materials which have undergone such a process are said to be tendered.

Nature of the Light. Little has been published concerning the light waves responsible for the deterioration of fibers, yarns, and fabrics. In 1883 Witz (7) found that less oxycellulose was formed in muslin when exposed under glass which absorbed toward the blue end of the spectrum. More recent writers (11) (29) (56) (57) agree that the deterioration is due to or increased by the short rays but particularly by the ultra-violet rays. Londolt (31) (32) (33) agrees that the tendering is due to the short rays—the blue to violet, but not necessarily the ultra-violet. Kauffman (29) reports that cotton alone is sensitive only to the ultra-violet rays but when sensitized by sodium uranate the fabric quickly becomes tender in visible light and gives reaction for oxycellulose.

Atmospheric Conditions. It is generally agreed that the tendering of cotton by light is increased by an increase in humidity.

The effect of moderate changes in temperature upon tendering of cotton has apparently been little studied, particularly within the range to which it is exposed in sunlight.

Borho (10) states that small quantities of acid or alkali in the atmosphere increase tendering, particularly acid. Sulphur dioxide from smoke may change to sulphuric acid and be the cause of tendering as reported by Wilkie (53).

Brugmann et al. (11) found that cellulose lost forty per cent of its strength when exposed to sunlight in oxygen and ten per cent in nitrogen. According to Barr and Hadfield (7) the loss in strength occurs most rapidly in oxygen, less rapidly in air, and to almost a negligible extent in vacuo, in hydrogen, or in carbon dioxide.

Nature of the Material. Zierhold (55) and Cunliffe and Farrow (19) found gray mercerized cotton more resistant to tendering by light than bleached unmercerized cotton, until forty to fifty per cent of the strength had been lost, when there was no appreciable difference in the tendering.

Cunliffe and Farrow (19) concluded: that fine yarns are more rapidly tendered than coarse but after long exposure the percentage loss may appear to be equal; that soft twisted yarns are more rapidly tendered than hard, both in the bleached and raw cotton; that doubles are less rapidly tendered than singles and that the area of the cotton exposed in the yarn probably influences the percentage loss in strength.

Nature of Dyes and Finishes. Certain dyes are known to protect fabrics from deterioration by light, while certain others accelerate the action. The tendering may take place upon exposure to light during the dyeing process while the dye is still in the reduced state. Various writers (14) (32) (34) (39) (40) state that yellow and orange or yellow and red dyestuffs are in general the vat dyes which tender cotton upon exposure to light. Indanthrene yellow G, Alizanthrene yellow 6 R, and Cibanone yellow G N were found to be exceptions among vat dyes (14) (34) (40). If a second dyestuff is present it may be oxidized preferentially to the cellulose or to the orange or yellow dyestuff (40).

Blue and violet vat dyes do not increase tendering. Landolt (32) explains this difference by Grotthus' photochemical law,—only those rays absorbed by the system can be effective in producing chemical action, so the action of light must be connected with the particular colors absorbed by the dyestuff. The yellow, orange, and red dyestuffs absorb the blue-violet and ultra-violet rays, which are the rays most active chemically.

Sulphur dyes may cause loss in strength due to the formation of free sulphuric acid formed by the oxidation of the color molecule, according to Byam (13), Matthews (36), and others (47).

Cunliffe and Farrow found that mineral chrome green protected cotton from tendering (19).

Two Russian writers (37) believe azo colors, indigo, indigosol, and indanthrene dyes greatly increase the tendering action of light.

Finishes may increase or decrease tendering, according to their ability to protect fibers from destructive light, or to initiate, increase, or decrease the formation of oxycellulose.

Smolens (43) claims that there is less tendency to make oxycellulose using hydrogen peroxide bleach than with chlorine bleach.

It is thought that iron, manganese, copper, and cobalt increase the deterioration of cotton when exposed to light and that the presence of alkali and acid accelerate the tendering action (13) (28) (29). Davidson's (20) experiments confirmed the belief of Barr and Hadfield (7) that the small amount of iron occurring in the cotton fiber itself may be responsible for some of the tendering.

Chemical Changes. The exact conditions of the chemical changes whereby cellulose is degraded are not definitely known. Various writers believe that hydrogen peroxide is formed as an intermediate product which produces tendering or fading, or both, and that light is necessary (33) for its formation, while others (29) believe light is not necessary. The dyestuffs themselves may enter into the reaction (24).

The various chemical reactions produce physical changes resulting in loss in strength and variation in color.

PLAN OF EXPERIMENT

Twenty-two white and colored common cotton fabrics, including bleached and unbleached muslins, ginghams, cotton suitings, and voiles, were chosen for this study. These fabrics were exposed to sunlight to determine the effect of such exposure upon the strength and color.

Physical and Chemical Analysis. An analysis of the structure of the yarns and fabrics was made. Tests were made to determine the kind and amount of size and finish in each fabric.

The Fabrics were Exposed Uncovered and in a horizontal position. The exposures were made between the hours of 8:30 a.m. and 4:30 p.m. on sunny days only, between May 22 and October 28, 1929, and in July, 1930. The exposure periods ranged from 25 to 375 hours inclusive, each period varying by 25 hours from the preceding or following period, making a total of 15 exposure periods. A record was kept of the hours of sunshine, the temperature, and relative humidity of each exposure period.

The Ultra-violet Radiation of the sunlight to which the fabrics were exposed was measured for a period of approximately one month, using the oxalic acid-uranyl sulphate method.

The Colors of the unexposed and exposed fabrics were measured spectrophotometrically to determine the changes in color occurring during each exposure period.

The Changes in Strength due to the exposure conditions were determined by comparing the breaking strength of strips of the fabrics exposed for the various periods of time with the breaking strength of the same fabrics before exposure.

The comparative extent to which the cellulose was degraded during selected exposure periods was determined for each fabric by the use of copper numbers.

The relative effects of structural and evironmental factors upon the change in strength due to exposure were determined by correlation analysis.

Comparisons were made of the changes in strength and color occurring in fabrics which differed in color, structure, type of dye, finish and size, price and guarantee.

FABRICS USED

Fabrics chosen for this study were those which could be purchased from a retail store and are available to the average consumer.

The twenty-two fabrics used were Pamico cloth, Yearround zephyr, Resilio voile, chiffon voile, English voile and Lonsdale, Hope, Puget Sound, and Lockwood muslins. The Yearround zephyr is a fine gingham such as is used in women's and children's dresses. The Pamico cloth is a cotton suiting of the type used in children's clothes, particularly little boys' suits. The voiles are fine fabrics of open weave. They are often used for women's and children's dresses, lingerie, and window curtains.

The Pamico cloth and Yearround zephyr were secured in white and five colors: blue, green, yellow, lavender, and pink. The Resilio voiles were blue, green, yellow, and lavender, but since white and pink could not be purchased in this brand a white "English" voile and a pink "chiffon" voile, made by the same company, were bought.[1] The Lonsdale and Hope muslins were bleached, the Lockwood slightly bleached, and the Puget Sound unbleached.[2]

The firms manufacturing these fabrics were requested to give such information concerning the finishes, dyes, and guarantees as they considered not secret.

Physical Analysis of Yarns and Fabrics

Methods.

All yarns and fabrics used in this study were analyzed as to structure, for the purpose of securing a complete description and to permit comparisons of the effects of structural factors upon the changes in strength and color resulting from exposure to sunlight.

The physical tests applied to the unexposed fabrics included determinations of fabric width, threads per inch, fabric thickness, weight per square yard, yarn size, ply, twists per inch, take-up, crimp, breaking strength of yarn and of fabric, and analysis of color. The physical analysis of the exposed fabrics included breaking strength and color analysis.

All physical tests were made under controlled atmospheric conditions, and after the specimens had been under these conditions for at least four hours. Specimens so treated are termed "conditioned". A constant condition of 65.0% relative humidity at 75° F. was chosen rather than the generally accepted standard of 65% relative humidity at 70° F. The latter was found more difficult to maintain in this region in the summer and was also found to be uncomfortably cool during the hot weather. It is be-

[1]The firm manufacturing the voiles has gone into liquidation since this study was begun.
[2]Trade names are used in this report with the consent of the manufacturers.

lieved that the chosen standard gave practically the same test results (52), and since all tests were made under the same conditions, results are comparable. The entire laboratory was maintained at this condition by the use of a Carrier unit air conditioner, equipped with steam for heating and ammonia cooling equipment for dehumidifying and cooling the air. With this equipment it was possible to maintain conditions within ±1% relative humidity and ±1° F. regardless of outside conditions. This is within the tolerance of ±1% and +10°F. approved by the textile committee of the American Society for Testing Materials, June, 1931.[1]

Width. The width of the fabric was determined by averaging the width taken at ten different places throughout the bolt. The cloth was laid flat and measured in a straightened but unstretched condition using a yard stick.

Weight. The conditioned weight per square yard was determined from strips ten inches in length and extending across the width of the fabric. These were conditioned for at least four hours and then weighed. The square inches in each strip were determined and from these figures was computed the weight per square yard. The average weight of three such strips was used for each of the twenty-two fabrics. All weighings, unless otherwise specified, were made on chainomatic balances.

Thickness. The thickness of each fabric was determined from the average of ten measurements distributed throughout the entire length of the fabric, all measurements being made at least six inches from the selvage. A Randell and Stickney thickness gauge, measuring a surface of 3/8 square inch in degrees of 1/1000 inch, was used. This method is not satisfactory for fabrics with pile, but since none of these have a pile and the lever was lowered gently from the same level each time there should be no inaccuracy due to crushing.

Thread Count. The thread count per inch was made with a Lowinson thread counter, averaging the results obtained from ten counts for each of filling and warp, distributed throughout the bolt of material.

Yarn Size. The yarn size or count was determined by raveling 100 yards each of warp and filling, weighing these in a conditioned state, and figuring their yarn size by the formula:

$$\text{Yarn size} = \frac{\text{no. of yards weighed}}{840 \times \text{weight in pounds}}$$

No sizing was removed.

Ply and Twist. For the determination of ply, twists per inch, and take-up, a Louis Schopper twist counter was used. The jaws were placed ten inches apart except for those single yarns which were too weak for this length. In the latter case the distance was two inches or in a few cases,

[1]Personal communication from Herbert J. Ball, Chairman of Committee D-13.

one inch, when single ply of high count was used. A uniform tension was applied to the yarn, the correct amount being determined by the formula:

$$\text{Tension (in grams)} = \frac{156 \text{ (constant)}}{\text{equivalent single size}} \qquad (17)$$

Take-up. The twist counter is equipped with a gauge for measuring take-up and from it was determined the percentage take-up due to twist, by dividing the difference in length before and after untwisting by the untwisted length and multiplying by 100. The average of 15 tests was used.

Crimp. The crimp was measured on the Schopper twist counter, the average of 15 measurements for each yarn being used. Ten inches of yarn as it lay in the fabric was marked, raveled, and placed between the jaws with the same tension as was used for yarn twist, and the length measured. The crimp was determined as defined by the A.S.T.M. (17) as the "difference in distance between any two points of the yarn as it lies in the fabric, and the same two points after the yarn has been removed from the fabric and straightened, expressed as a percentage of the distance between the two points as the yarn lies in the fabric".

Breaking Strength of Fabrics. The breaking strength tests of both fabrics and yarns were made on a Scott power tester of the vertical combination type, having an automatic recording device and with capacities of 0-55 pounds and 0-110 pounds. The strip method was used for breaking strength. Two-inch jaws were used with a distance of three inches between jaws and a rate of speed of twelve inches per minute (12). Strips of fabrics were cut 6 to 7 inches long and 1¼ inches in width and raveled back on each side until the strips were exactly one inch wide by thread count. Each strip was clamped between the jaws with uniform tension and with the crosswise threads parallel with the jaws. Both warp and filling tests were made in the same way.

Breaking Strength of Yarns. The breaking strength of yarns was measured by removing from strips of fabrics containing 100 yarns, the center crosswise yarns for a depth of three inches, leaving enough of the woven fabric at each end to fasten in the two jaws. The fabric was placed between the jaws of the Scott tester so the edge of the raveled strip coincided with the edge of the jaw, leaving exactly 3 inches between the jaws. The average of twenty tests of the warp and of twenty tests of the filling was considered the strength of 100 threads without the effect of interlacing threads. This method has since been described by Hess (26) (38).

Strength Due to Interlacing of Threads. An analysis was made of the strength of each fabric due to the interlacing of threads in the weaving, or to the drag or cohesiveness imparted by the finishing processes. The average breaking strength of twenty fabric strips, each one inch in width, was compared with the average breaking strength of an equal number of yarns, the yarn specimens being prepared in the same manner as for the multiple strand test described in the preceding paragraph.

Strength-count Factors. The strength-count factors were determined by dividing the breaking strength of 100 yarns by the yarn size.

Strength-weight Factors. The strength-weight factors were determined by dividing the breaking strength by the weight in ounces per square yard.

Twist-constants. The twist-constants were obtained by dividing the twists per inch by the square root of the yarn size.

Moisture Content. The abilities of the various fabrics to take up moisture were compared on the basis of the moisture in the conditioned specimens. Three specimens were first conditioned for four hours as previously described, and then weighed. These specimens were then kept in an Emerson eight basket oven with a temperature range within 220° to 230° F. until two consecutive weighings made at ten-minute intervals showed a constant weight or a further loss of less than 0.1% from the previous weighing (17). The average loss from the conditioned weight represented the moisture content and was expressed in percentage of the conditioned weight.

Color Analysis. Analyses of color were made by measuring the color stimuli in terms of percentage reflection and wave length using a Keuffel and Esser Spectrophotometer. A magnesium carbonate block with an assumed reflection of 100% at every wave length was used as a standard. The reflection of the specimen expressed in percentage of the standard was determined from the average of ten readings made at intervals of twenty millimicrons, from 440 to 700 millimicrons (30).

Results.

Price and Width. A comparison of the prices per linear yard of the zephyrs and Pamico cloths shows a difference of ten cents, as shown in Table 1. When the prices per square yard are compared there is a difference of approximately five cents. A similar relative difference is shown in the unbleached muslins. These differences in price per unit measure emphasize the importance of consideration of the width of a fabric when making purchases.

Weight and Thickness. Ranked in order of conditioned weight per square yard are Pamico cloths, unbleached muslins, bleached muslins, zephyrs, and voiles. The Pamico cloths and muslins fall in the same order in respect to thickness. The zephyrs and voiles are of approximately the same thickness although the zephyrs are heavier, chiefly because of closer weave.

Thread Count. The Pamico cloths have the lowest thread count of the five types of fabrics. The zephyrs and bleached muslins contain more threads per inch than the other fabrics. The open weave of the voiles, which is a characteristic of this type of fabric, requires a comparatively low thread count. On account of the heavier yarns of the Pamico cloths fewer threads per inch are needed, with a resulting greater uniformity of thread count than in any of the other fabrics.

Yarn Size. Ranked in order of yarn sizes are Pamico cloths as the coarsest, followed by unbleached muslins, bleached muslins, zephyrs, and voiles. These yarn sizes vary from the equivalent of 11 singles to 55 singles.

Table 1. Physical analysis of fabrics

Fabric	Price		Width inches	Thick-ness inches	Conditioned wt. in oz. per sq. yard	% Moisture (conditioned 4 hours)	Thread count		Yarn size		Percentage crimp	
	Linear yard	Square yard					Warp	Fill-ing	Warp	Fill-ing	Warp	Fill-ing
Yearround Zephyr:												
White	$0.49	$0.551	32.00	0.0071	2.876	6.21	84.3	76.4	40.89	34.90	4.45	16.05
Blue	0.49	0.547	32.25	0.0070	2.730	6.13	84.2	76.3	42.57	38.52	3.90	14.25
Green	0.49	0.547	32.25	0.0070	2.776	6.53	84.3	76.2	42.28	39.39	6.03	17.00
Yellow	0.49	0.549	32.12	0.0068	2.786	6.40	84.4	76.1	42.90	38.07	4.25	16.25
Lavender	0.49	0.551	32.00	0.0071	2.788	6.70	84.2	76.1	44.86	40.56	3.55	17.25
Pink	0.49	0.549	32.12	0.0073	2.701	7.14	84.4	76.3	41.88	38.13	3.90	15.55
Pamico Cloth:												
White	0.59	0.594	35.75	0.0150	4.677	7.82	40.0	38.0	2/22s	2/26s	4.62	18.65
Blue	0.59	0.596	35.61	0.0149	4.723	8.01	40.0	38.0	2/22s	2/28s	3.70	19.40
Green	0.59	0.595	35.72	0.0151	4.732	7.88	40.0	38.0	2/22s	2/28s	2.25	17.35
Yellow	0.59	0.598	35.30	0.0149	4.476	7.71	40.0	38.0	2/22s	2/30s	3.15	19.75
Lavender	0.59	0.603	35.25	0.0149	4.471	7.44	40.0	38.0	2/22s	2/28s	4.28	18.60
Pink	0.59	0.590	36.00	0.0143	4.615	7.84	40.0	38.0	2/22s	2/26s	2.98	13.90
Voiles:												
White	0.65	0.600	39.00	0.0071	1.618	7.63	58.3	56.2	52.00	48.00	5.83	8.70
Blue	0.65	0.620	37.75	0.0073	1.623	7.10	58.1	56.3	2/105s	2/100s	7.43	11.35
Green	0.65	0.608	38.50	0.0073	1.540	7.59	58.4	56.2	2/100s	2/100s	6.54	12.05
Yellow	0.65	0.616	38.00	0.0071	1.617	7.68	58.4	56.3	2/110s	2/110s	6.15	9.65
Lavender	0.65	0.612	38.25	0.0075	1.610	8.41	58.1	56.2	2/110s	2/110s	7.38	10.00
Pink	0.65	0.616	38.00	0.0073	1.667	6.33	64.4	56.3	2/105s	2/100s	8.10	12.43
Muslins:												
Hope	0.19	0.190	36.00	0.0086	3.357	6.72	77.0	69.3	30.32	30.85	5.60	17.05
Lonsdale	0.21	0.213	35.50	0.0093	3.486	6.59	82.8	80.2	29.62	38.02	6.15	18.90
Lockwood	0.25	0.231	39.00	0.0124	4.223	7.33	68.5	70.7	21.19	26.81	11.80	12.10
Puget Sound	0.17	0.167	36.75	0.0124	3.853	7.79	59.8	55.5	17.74	30.21	6.85	12.60

Crimp. In all fabrics the crimp is approximately two to four times as great in the filling as in the warp. This shows the usual greater tension in the warp yarns. The warp and filling yarns of the Lockwood muslin show almost equal crimp.

Ply and Twist. The fabrics are composed of single ply yarns with the exceptions of the Pamicos and colored voiles.

The twists of the yarns are placed on a comparable basis by the use of the twist constants as given in Table 2. The warp yarns of the fabrics composed of single yarns are all of higher twist than the filling. Within each fabric the warp and filling are twisted in the same direction.

The yarns of the colored voiles have a right-hand twist in both single and double yarns. This combination of twists together with a high twist factor results in a fine hard yarn. The Pamicos have a right-hand twist in the singles with a left-hand twist in the doubles. This reversal of twists makes a compact but comparatively pliable yarn.

Take-up. The percentage take-up corresponds closely to the twists per inch, varying slightly among the colors of the same type of fabric.

Strength of Fabrics and Yarns. The Pamico cloths have the greatest fabric breaking strength, as is to be expected from the type of fabric. However, there is greater difference between the breaking strength of the warp and filling of the Pamicos than in any other fabric, the filling being much weaker than the warp. The fillings of the Pamicos are of approximately the same strength as the zephyr warps. In all fabrics the warp strips are stronger than the filling strips although they are nearly equal in the Lockwood muslin.

Table 2. Analysis of ply and twist of yarns

Fabric	Yarn twist								Twist constant[1]	
	Warp				Filling					
	Ply	Doubles	% Take up	Singles	Ply	Doubles	% Take up	Singles	Warp	Filling
Yearround Zephyr:										
White	1			R 23.5	1			R 19.2	3.68	3.25
Blue	1			R 26.9	1			R 18.1	4.12	2.92
Green	1			R 28.3	1			R 21.2	4.35	3.38
Yellow	1			R 26.5	1			R 20.0	4.08	3.24
Lavender	1			R 25.6	1			R 19.8	3.82	3.11
Pink	1			R 27.5	1			R 21.2	4.25	3.43
Pamico Cloth:										
White	2	L 12.6	0.79	R 13.7	2	L 16.5	2.93	R 17.6	3.80/2.92	4.58/3.45
Blue	2	L 12.1	0.81	R 15.3	2	L 16.9	3.03	R 18.3	3.65/3.26	4.52/3.46
Green	2	L 11.9	1.42	R 11.1	2	L 16.5	4.69	R 22.9	3.59/2.37	4.41/4.33
Yellow	2	L 11.7	0.64	R 14.6	2	L 17.8	3.96	R 22.0	3.53/3.11	4.60/4.02
Lavender	2	L 12.1	1.18	R 13.8	2	L 17.2	3.59	R 19.1	3.65/2.94	4.60/3.61
Pink	2	L 12.2	0.75	R 10.9	2	L 17.3	4.39	R 17.9	3.68/2.32	4.80/3.51
Voiles:										
White	1			R 31.3	1			R 36.3	4.34	5.24
Blue	2	R 33.6	7.48	R 37.5	2	R 36.1	8.91	R 35.0	4.64/3.66	5.10/3.51
Green	2	R 34.3	8.25	R 34.9	2	R 37.1	9.50	R 30.4	4.85/3.49	5.25/3.04
Yellow	2	R 33.3	8.36	R 31.0	2	R 37.2	10.46	R 30.7	4.49/2.96	5.02/2.93
Lavender	2	R 33.1	7.19	R 36.8	2	R 35.5	9.29	R 34.4	4.46/3.51	4.88/3.28
Pink	2	R 37.2	8.80	R 35.8	2	R 39.4	9.45	R 35.2	5.14/3.49	5.57/3.52
Muslins:										
Hope	1			R 25.3	1			R 21.2	4.60	3.83
Lonsdale	1			R 24.5	1			R 19.8	4.50	3.21
Lockwood	1			R 24.1	1			R 19.6	5.24	3.79
Puget Sound	1			R 19.7	1			R 21.8	4.68	3.97

[1]Twists per inch divided by the square root of the yarn size.

The strength-weight factors given in Table 3 place all fabrics on a comparable basis for a study of strength in respect to weight. It is noted that there is a difference in relative strengths on this basis, the voiles being first, followed by the zephyrs, then the Pamicos and muslins of approximately the same strength. This comparison shows that fine, tightly twisted yarns have greater strength for the same weight than coarse, loosely twisted yarns.

The breaking strength of the yarns can be most easily compared by the use of the strength-count factors as given in Table 3. From this comparison it is seen that the yarns have the same relative strength as the fabrics. The difference in strength between the warp and filling of the Pamico cloth is particularly noticeable in the strength-count factors.

Table 3. Breaking strength, strength-count, and strength-weight

Fabric	Breaking strength of one-inch fabric strips in pounds		Breaking strength of 100 yarns in pounds		Strength-count factor[1]		Strength-weight factor[2]
	Warp	Filling	Warp	Filling	Warp	Filling	
Yearround Zephyr:							
White	37.95	34.32	14.68	12.64	0.36	0.36	25.13
Blue	36.27	28.02	15.86	12.54	0.37	0.33	23.55
Green	33.35	25.53	14.07	11.21	0.33	0.29	22.29
Yellow	36.73	30.33	15.36	13.93	0.36	0.37	24.07
Lavender	37.91	34.63	15.64	14.64	0.35	0.36	26.02
Pink	31.83	26.00	15.07	10.57	0.40	0.28	21.41
Pamico Cloth:							
White	62.39	36.88	66.82	39.46	6.15	3.11	21.23
Blue	55.37	33.88	60.25	35.39	5.65	2.60	18.90
Green	58.98	38.43	63.27	42.43	5.94	3.07	20.59
Yellow	54.24	29.88	61.23	33.62	5.41	2.18	18.79
Lavender	56.21	36.70	64.37	36.91	6.01	2.70	20.78
Pink	59.48	38.00	60.41	42.34	5.53	3.15	21.12
Voiles:							
White	21.80	18.30	11.84	10.20	0.23	0.21	24.78
Blue	28.61	24.13	18.86	15.06	0.36	0.31	32.50
Green	28.57	22.37	17.20	13.55	0.34	0.28	33.08
Yellow	27.26	22.70	17.40	12.77	0.32	0.25	30.90
Lavender	27.78	23.13	15.97	14.44	0.29	0.30	31.62
Pink	30.65	24.30	19.09	17.97	0.37	0.37	32.96
Muslins:							
Hope	40.84	31.55	22.57	17.93	0.74	0.58	21.56
Lonsdale	37.64	27.87	20.43	13.07	0.69	0.34	18.79
Lockwood	46.70	45.03	33.39	19.18	1.58	0.72	21.72
Puget Sound	49.70	32.20	37.18	20.02	2.10	0.67	21.26

[1]Strength of 100 yarns divided by the yarn size.
[2]Breaking strength of warp plus filling divided by the weight in ounces of one square yard.

Effect of Interlacing. The effect of interlacing of yarns on the fabric breaking strength is given in Table 4. It is noted that in all fabrics except the muslins the strength of warps and fillings was increased to approximately the same extent although when the averages for each class of fabric are compared the filling shows a slightly greater increase. There is greater relative difference in favor of the filling in the muslins, particularly the unbleached. This is probably due to the influence of size in these fabrics. The increase in strength imparted by interlacing cannot be attributed to any one factor but is undoubtedly due to a combination of yarn size, thread count, twist, crimp, kind and amount of size and finish.

Moisture Content. The moisture content of each fabric after being conditioned for four hours was expressed as percentage of the conditioned weight, as given in Table 1. These figures show that under atmospheric conditions of 65 per cent relative humidity at 75° F. most of the fabrics absorbed more than the 6½ per cent generally accepted as standard moisture content for cotton. In general the voiles, Pamicos, and unbleached muslins absorbed more moisture. It seems doubtful if these slight differences in absorbtive ability had much effect on the tendering or fading of these fabrics.

Table 4. Effect of interlacing of yarns on fabric strength

Fabric	Warp: Breaking strength in pounds — Fabric	Warp: Breaking strength in pounds — Yarn	Warp: % Strength due to interlacing	Filling: Breaking strength in pounds — Fabric	Filling: Breaking strength in pounds — Yarn	Filling: % Strength due to interlacing
Yearround Zephyr:						
White	37.95	12.37	67.40	34.32	9.66	71.85
Blue	36.26	13.35	63.18	28.02	9.56	65.88
Green	33.35	11.86	64.44	25.53	8.55	67.04
Yellow	36.72	12.96	64.71	30.33	10.59	65.08
Lavender	37.90	13.17	65.22	34.63	11.14	67.83
Pink	31.82	12.71	60.06	26.00	8.06	69.00
Pamico Cloth:						
White	62.39	26.72	57.17	36.83	14.99	59.30
Blue	55.37	24.09	56.49	33.88	13.45	60.30
Green	58.97	25.30	57.10	38.43	16.12	58.05
Yellow	54.24	24.49	54.85	29.88	12.78	57.23
Lavender	56.20	25.74	54.20	36.70	14.03	61.77
Pink	59.47	24.16	59.37	38.00	16.09	57.66
Voiles:						
White	21.80	6.90	68.35	18.30	5.73	68.69
Blue	28.60	10.95	61.71	24.13	8.47	64.90
Green	28.56	10.04	64.85	22.37	7.61	65.98
Yellow	27.26	10.15	62.77	22.70	7.18	68.37
Lavender	27.77	9.27	66.62	23.13	8.11	64.94
Pink	30.64	12.29	59.89	24.30	10.11	58.40
Muslins:						
Hope	40.84	17.37	57.47	31.55	12.42	60.63
Lonsdale	37.64	16.91	55.07	27.86	10.48	62.38
Lockwood	46.70	23.60	49.46	45.03	13.14	70.82
Puget Sound	49.70	22.23	55.27	32.20	11.16	65.34

Chemical Analysis of Sizes and Finishes

Sizes and finishes are applied to fabrics for the purpose of aiding in the process of manufacture or to produce certain chemical and physical properties in the finished product (44). Tests were made to determine the presence of a few of the substances commonly used in sizing and finishing.

Methods. All tests were made either in duplicate or triplicate. Quantitative tests were made on warp and filling yarns separately. The fats and waxes were extracted with carbon tetrachloride in a Soxhlet apparatus. The total size and finish was determined by extracting water-soluble substances, fats and waxes, stripping with caustic soda, hydrochloric acid and ashing for china clay (42).

Qualitative tests were made for china clay, glue or gelatin, dextrin, sugar, starch, chloride ions, sulphate ions, magnesium, barium, calcium, and zinc.

Results. The results of these tests are given in Table 5.

Table 5. Analysis of finish and size

Fabric	Finishes and sizes								
	Starch	Sugar	Glue or Gelatin	Chloride	Sulfate	% Fats and Waxes		% Total finish and size	
						Warp	Filling	Warp	Filling
Yearround Zephyr:									
White	—	—	trace	—	—	0.82	0.74	0.92	0.78
Blue	+	—	—	—	—	0.70	1.12	1.17	2.02
Green	+	—	—	—	—	0.94	1.84	2.81	2.59
Yellow	+	—	—	—	—	0.69	0.85	1.69	2.54
Lavender	+	—	—	—	—	1.26	0.35	1.41	2.50
Pink	—	—	—	—	—	1.67	1.68	1.67	1.75
Pamico Cloth:									
White	—	—	—	—	+	0.27	0.62	1.30	1.75
Blue	—	—	—	trace	+	0.43	0.33	1.77	1.79
Green	—	—	—	—	—	0.26	0.46	1.39	1.67
Yellow	—	—	—	—	+	1.14	1.00	1.76	2.19
Lavender	—	—	—	—	—	0.48	0.70	1.09	1.07
Pink	—	—	—	—	—	0.50	0.72	1.35	1.03
Voile:									
White	+	trace	—	—	—	0.46	0.40	1.63	2.36
Blue	—	—	—	+++	++	0.51	0.93	5.19	7.82
Green	—	—	—	+	++	0.91	0.75	5.74	3.93
Yellow	—	—	—	—	++	0.55	0.59	4.13	4.36
Lavender	—	—	—	trace	++	0.63	0.94	4.44	4.76
Pink	—	—	—	+	++	1.12	0.88	4.12	5.85
Muslins:									
Hope	+	—	—	—	—	0.78	1.05	1.74	2.92
Lonsdale	+	—	—	—	—	1.80	1.44	1.89	2.90
Lockwood	++	—	+	—	—	0.58	1.09	11.09	3.41
Puget Sound	++	—	+	—	+	2.58	1.68	20.08	4.46

No corrections were made for mechanical losses. The figures obtained for china clay were so small as to come well within the limits of experimental error. The difference in the solubility of dyes in acid and neutral solutions introduced variations sufficient to account for the figures on dry weights of clay; therefore it was concluded little if any china clay had been used. The figures in the table show that all finishes present were not determined. The sulphate ions found in three of the Pamico cloths were probably the result of the hydrosulphite being oxidized into sodium bisulphate. The only apparent explanation for the trace of chloride ions in the blue Pamico is that it came from the calcium hypochlorite used for bleaching.

The zephyrs, Pamicos, and bleached muslins show much less total size and finish than the voiles and unbleached muslins. The largest amount of extracted substances was obtained from the warps of the unbleached muslins, evidently due to heavy sizing of these yarns before weaving.

The colored voiles gave positive tests for more of the substances for which tests were made than any of the other fabrics. They also contained a larger quantity of total size and finish than any others with the exception of the unbleached muslins.

SAMPLING

It is conceded that random sampling is theoretically superior to any systematic arrangement, but due to the large number of specimens and the necessity of removing some before exposure and others at comparatively frequent intervals, a systematic method seemed more practicable for this study. According to Turner (50) the method adopted may be considered systematic random. A very similar method was used by Turner, criticized by Tippett (48), and defended by Turner (50), who, while he considers the random method superior (since it avoids any periodicity occurring), proves the systematic sampling did not vitiate his results. Cunliffe and Farrow (19) used a similar method, likewise using the same yarns in unexposed and exposed specimens.

Figure 1 shows the method of sampling the warp.

The specimens were marked with pencil across the fabric in four sets, each containing three specimens. Five such crosswise sets were placed consecutively lengthwise of the fabric so that each column contained five treatments. Each specimen was marked with a letter so its position in relation to other specimens could be determined. Such a grouping as described contained sixty specimens. At least two more such groupings were taken from the bolt of fabric making a total of at least 180 specimens from each fabric. All pencil marks were placed near the end of the strip so that this portion of the specimen could be excluded from all tests.

The use of drawn threads assisted in securing identical yarns for comparison. Each specimen contained the average number of threads in one inch, counting from the drawn thread. In determining the breaking strength of the fabric, the unexposed specimens in each column were averaged and used as a basis for comparison with the average of the exposed specimens in the same column. The final result for each exposure period was determined by averaging the results of the several columns as expressed in percentage loss or gain from the original. Since each column contained three specimens for each exposure and there were at least three columns, nine or more specimens were used to determine the average breaking strength for each exposure period.

The average of three tests of the same yarns should be fairly representative of those yarns and assist in avoiding errors due to any periodicity which might occur. Since each warp specimen contains many different threads (the number in one inch), they have an averaging effect not found in the filling where the same yarn is often repeated. Consequently the warp strips tend to give smaller probable errors of the means than the filling strips (51).

The specimens of the filling were likewise marked in sets of three with five treatments between the selvages and as many repeats in the warp direction of the fabric as necessary to secure the required number of specimens. Except for the fact that there appeared only one of any treatment in each column, the comparisons were made as for the warp.

SELVAGE

SEVEN INCHES

ORIG 1 A	ORIG 2 A	ORIG 3 A	125 4 A	125 5 A	125 6 A	225 7 B	225 8 B	225 9 B	325 10 A	325 11 A	325 12 A	HOURS OF EXPOSURE COLUMN NUMBER GROUP LETTER DRAWN THREAD
25 1 A	25 2 A	25 3 A	ORIG 4 B	ORIG 5 B	ORIG 6 B	250 7 B	250 8 B	250 9 B	350 10 B	350 11 B	350 12 B	
50 1 A	50 2 A	50 3 A	125 4 B	125 5 B	125 6 B	ORIG 7 B	ORIG 8 B	ORIG 9 B	375 10 B	375 11 B	375 12 B	
75 1 A	75 2 A	75 3 A	150 4 B	150 5 B	150 6 B	275 7 B	275 8 B	275 9 B	ORIG 10 B	ORIG 11 B	ORIG 12 B	
100 1 A	100 2 A	100 3 A	175 4 B	175 5 B	175 6 B	300 7 B	300 8 B	300 9 B	400 10 B	400 11 B	400 12 B	
ORIG 1 B	ORIG 2 B	ORIG 3 B	200 4 B	200 5 B	200 6 B	ORIG 7 C	ORIG 8 C	ORIG 9 C	325 10 B	325 11 B	325 12 B	
25 1 B	25 2 B	25 3 B	ORIG 4 C	ORIG 5 C	ORIG 6 C	225 7 C	225 8 C	225 9 C	ORIG 10 C	ORIG 11 C	ORIG 12 C	
50 1 B	50 2 B	50 3 B	125 4 C	125 5 C	125 6 C	250 7 C	250 8 C	250 9 C	350 10 C	350 11 C	350 12 C	
75 1 B	75 2 B	75 3 B	150 4 C	150 5 C	150 6 C	275 7 C	275 8 C	275 9 C	375 10 C	375 11 C	375 12 C	
100 1 B	100 2 B	100 3 B	175 4 C	175 5 C	175 6 C	300 7 C	300 8 C	300 9 C	400 10 C	400 11 C	400 12 C	
ORIG 1 C	ORIG 2 C	ORIG 3 C	200 4 C	200 5 C	200 6 C	ORIG 7 A	ORIG 8 A	ORIG 9 A	325 10 C	325 11 C	325 12 C	

SELVAGE

Fig. 1. Method of sampling the warp.

By comparing each exposure with the unexposed in that column only, it was possible to avoid any variation in strength due to the insertion of new bobbins. The average of the variation for the same treatment in the various columns was used as the final figure. This method gave at least nine specimens for each treatment.

Since the purpose of this study was to determine change in strength and not the average strength, it was thought that this method of comparing the same yarns would give as accurate results as a more random sampling, which would require more time and labor. To determine this point specimens from random sampling were compared with an equal number from the adopted method. In all cases the probable errors were determined by correcting for the small number of observations according to R. A. Fisher's method.[1]

Table 6 shows the results of this comparison.

Table 6. Comparison of averages of samples obtained by adopted and random methods

Adopted method			Random		
Mean and probable error. Pounds	S. D.	Probable error as % of mean	Mean and probable error. Pounds	S. D.	Probable error as % of mean
41.39 ± 0.36	1.51	0.87	40.38 ± 0.36	1.52	0.90
60.78 ± 0.71	2.99	1.17	56.33 ± 0.42	1.76	0.75
62.22 ± 0.28	1.16	0.44	61.61 ± 0.83	3.50	1.35
49.66 ± 0.41	1.73	0.89	48.89 ± 0.45	1.88	0.91
48.83 ± 0.45	1.89	0.92	47.89 ± 0.73	3.04	1.51
38.22 ± 0.54	2.25	1.40	38.77 ± 0.56	2.34	1.44
35.94 ± 0.29	1.21	0.80	36.50 ± 0.54	2.26	1.48
37.78 ± 0.36	1.49	0.94	39.06 ± 0.51	2.13	1.30

With the exception of one case the probable error as a percentage of the mean was smaller in the adopted method than in the random. It was therefore concluded that the method used was as satisfactory as the random method, using the same number of tests.

Fabrics were then prepared by the random Latin square method using five treatments to each square, which most resembled the grouping used in this study. These specimens were tested and the results compared with those obtained on the same fabrics by the adopted method.

Table 7 shows these comparisons.

The adopted method gave lower probable errors as percentage of the mean in eighteen of the twenty-nine samples than did the random Latin square method. From this comparison it was concluded that the method used gave as reliable results as probably would have been obtained with the random Latin square. Also any variations due to the occurrence of periodicity in the fabric was probably excluded in the final correlations where the numbers used were those obtained by fitted curves.

[1]Ezekiel, Mordecai, 1930. Methods of correlation analysis. P. 19.

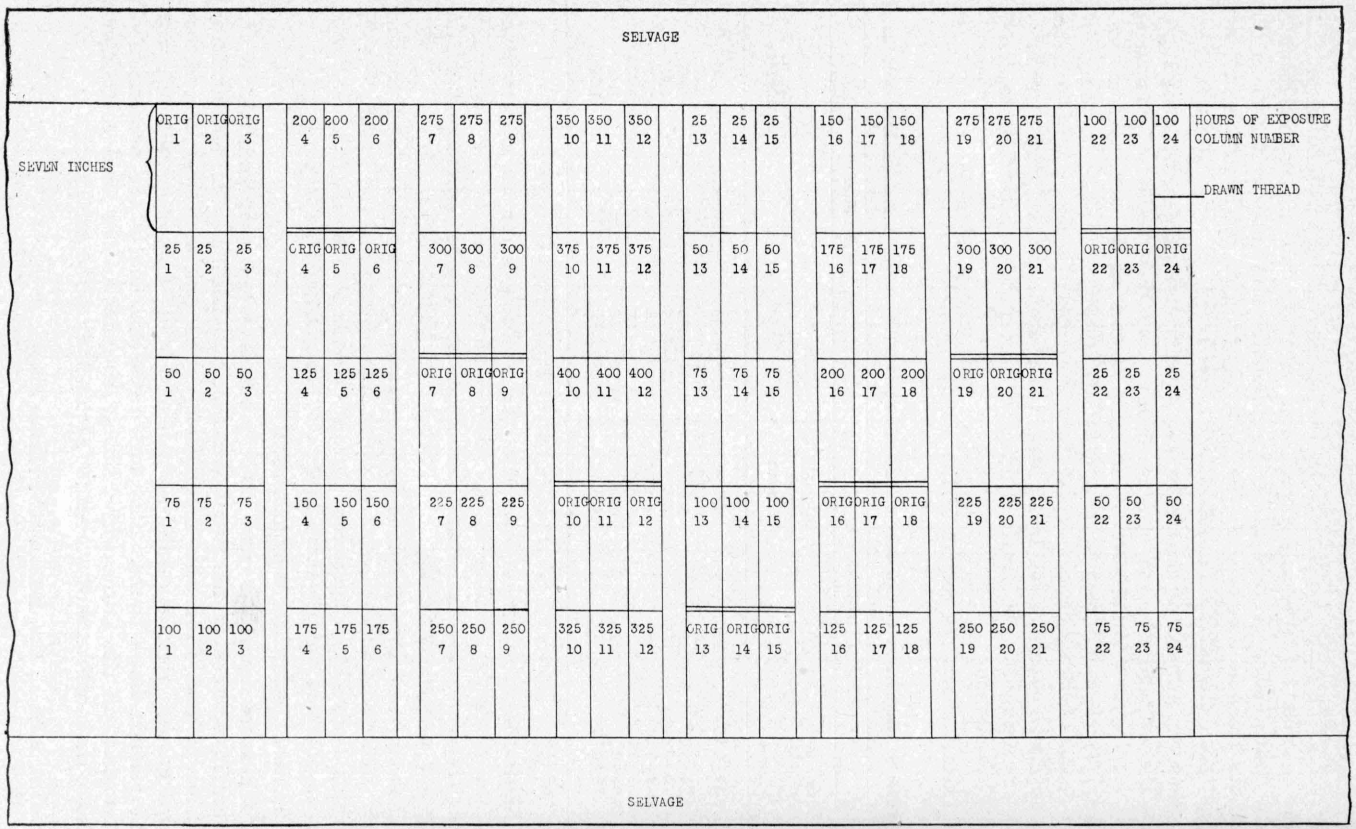


Fig. 2. Method of sampling the filling.

To determine the reliability of the results obtained from the number

Table 7. Comparison of averages of breaking strengths of samples obtained by adopted and random Latin square methods

Adopted method			Random Latin Square		
Mean and probable error. Pounds	S. D.	Probable error as % of mean	Mean and probable error. Pounds	S. D.	Probable error as % of mean
24.00±0.39	0.82	1.62	22.30±0.38	1.12	1.70
23.33±0.38	0.80	1.64	22.10±0.47	1.39	2.13
22.33±0.11	0.24	0.51	22.50±0.26	0.77	1.16
22.00±0.19	0.41	0.88	22.30±0.23	0.68	1.03
22.00±0.41	0.87	1.88	22.30±0.45	1.33	2.01
27.33±0.11	0.24	0.42	25.30±0.23	0.68	0.90
27.67±0.41	0.85	1.47	25.70±0.50	1.47	1.93
26.50±0.39	0.82	1.47	25.60±0.55	1.62	2.14
27.17±0.41	0.85	1.49	25.00±0.21	0.63	0.85
27.17±0.41	0.85	1.49	25.60±0.27	0.80	1.05
30.33±0.41	0.85	1.34	33.50±0.64	1.91	1.92
31.66±0.74	1.55	2.33	34.10±0.07	0.02	0.20
31.66±0.56	1.18	1.78	33.80±0.41	1.21	1.21
31.83±0.45	0.94	1.42	33.70±0.69	2.04	2.04
33.66±0.79	1.65	2.34	34.70±0.50	1.47	1.43
26.16±0.11	0.24	0.43	29.50±0.53	1.58	1.81
27.00±0.50	1.04	1.84	28.60±0.29	0.86	1.01
25.17±0.41	0.85	1.61	29.80±0.51	1.50	1.70
27.83±0.11	0.24	0.41	28.90±0.47	1.39	1.63
27.11±0.59	0.86	2.18	30.00±0.37	1.10	1.23
62.33±0.81	1.70	1.30	62.90±0.55	1.16	0.88
63.66±0.57	1.21	0.90	62.20±1.65	3.46	2.65
60.83±1.33	2.78	2.18	62.70±0.31	0.64	0.49
43.50±0.34	0.71	0.78	41.40±0.63	1.56	1.53
40.50±0.89	1.87	2.20	41.20±0.20	0.59	0.48
41.33±0.30	0.62	0.72	40.80±0.48	1.44	1.19
32.33±0.49	1.03	1.52	33.70±0.49	1.46	1.45
31.00±0.78	1.63	2.51	31.00±0.91	2.70	2.94
30.83±0.49	1.03	1.59	31.70±0.54	1.61	1.71

of specimens used, 45 specimens were treated statistically in groups as shown in Table 8.

To obtain a probable error as percentage of the mean of less than 0.5, it is evident that 45 or more specimens would have been necessary. Fifteen specimens would probably have kept this percentage under 1, but in groups containing nine specimens it did not exceed 1.4, with two of the five cases under 1.

When the probable errors of the samples are compared, it is noted that fifteen or more specimens would be necessary to give probable errors under 0.5 pound, which is the smallest division of the dial on the breaking strength machine. Comparisons of the results of the five groups containing nine specimens with the five groups containing seven specimens show that in each case two of the five samples had a probable error above 0.5 pound with the samples of seven specimens with probable errors lower than the samples of five specimens. In the ten samples containing five specimens each, the probable errors were above 0.5 pound with two exceptions.

From these results it was concluded that fifteen or more specimens would give better results than nine, the number used, but that there was not sufficient difference between nine and a larger number to justify the

Table 8. Comparison of various numbers of specimens

Number of specimens	Mean and probable error. Pounds	S. D.	Probable error as % of mean
45	41.08±0.21	2.09	0.52
40	41.06±0.23	2.10	0.55
35	39.91±0.22	1.91	0.55
30	41.13±0.26	1.80	0.55
25	41.20±0.27	1.93	0.64
20	41.45±0.30	1.96	0.73
15	41.50±0.39	2.17	0.94
9	42.89±0.35	1.47	0.81
9	40.50±0.55	2.30	1.36
9	40.50±0.45	1.89	1.11
9	40.89±0.58	2.43	1.42
9	40.89±0.40	1.68	0.98
7	42.14±0.34	1.25	0.83
7	40.14±0.63	2.28	1.56
7	40.78±0.48	1.75	1.18
7	41.07±0.72	2.61	1.75
7	40.43±0.45	1.64	1.11
5	40.60±0.58	1.71	1.42
5	40.50±0.65	1.92	1.60
5	41.60±0.78	2.30	1.86
5	43.10±0.69	2.05	1.60
5	42.00±0.41	1.22	0.98
5	40.30±0.53	1.57	1.31
5	40.00±0.65	1.92	1.62
5	40.70±0.66	1.96	1.63
5	39.20±0.51	1.50	1.29
5	42.10±0.49	1.46	1.17

additional time and labor involved. Seven specimens gave nearly as good results as nine and only slightly better than five specimens, the number recommended by the American Society for Testing Materials (17).

It is believed that the method of locating specimens and the size of the sample used in this study, gave sufficiently accurate results.

METHOD OF EXPOSURE

Light Source. Sunlight was used as the light source with no attempt to substitue an artificial light since no light on the market will give exactly the same wave lengths or results in degree, kind, or time of fading. Although a carbon arc lamp such as is used in the Fade-Ometer gives an artificial light more closely resembling sunlight than any other, the fading of some dyes by the two light sources is different. According to the manufacturers (27) the Fade-Ometer causes blues and violets to fade somewhat less and yellows, oranges, and greens more than sunlight. So far as known, no work has been published comparing the tendering effects of a Fade-Ometer and sunlight. Neither does it seem possible to compare the tendering effect of these various lights with that of Texas sunlight until more is known of the composition of the sunlight, which varies from season to season, day to day, and even hour to hour. While in some localities it has been found that 1.3 hours of June sunlight in the "standard sun test" (15) is equivalent to approximately one hour under a carbon arc lamp (16), so far as known no definite relationship has been determined for sunlight in this section of Texas, which must obviously be different from localities where altitudes, rainfall, and seasons differ. The determination of the effect of Texas sunlight on the tensile strength and color of cotton fabrics seemed to justify the use of the sunlight itself.

Fabrics Exposed Uncovered. The fabrics were exposed uncovered although a cover of window glass is used in the standard sun test. A duplication, so far as possible, of conditions under which the fabrics might be worn was desired. Any practicable glass cover would have eliminated some of the wave lengths known to fade certain dyes and thought to be important in producing tendering, as well as influenced the temperature and the free movement of the air. The only purpose of a cover is to protect the fabrics from dust and sudden showers. Exposures were made upon the roof of a three-story building. The building was sufficiently isolated to receive no smoke, and high enough to receive no shadows and to avoid most of the dust. The roof was somewhat protected from wind by a parapet. These circumstances made it possible to expose the fabrics without covers.

Mounting of Specimens. The specimens, which had been marked for exposure as described under sampling, were fastened with thumb tacks to 3 by 4-feet beaver boards and the boards laid upon the flat roof.

Periods of Exposures. The exposures herein reported were made within the periods of May 22 to October 28, 1929, and July 3 to July 21, 1930, inclusive. The fabrics were exposed only on those days when the sky was relatively free from clouds. The long summers and long sunny days made it possible to obtain a total of 300 hours the first season, never exposing more than five days in any one week, or more than eight hours on any one day. All exposures were made between 8:30 a.m. and 4:30 p.m., or as the days became shorter, between 9 a.m. and 4 p.m.

Atmospheric Conditions. A record of the atmospheric pressure, hours of sunshine, relative humidity, and temperature was kept during the hours of exposure. A Friez automatic sunshine recorder made it possible not only to determine accurately the number of hours of sunshine but the time and duration of the periods when the sun was behind a cloud. The relative humidity and temperature were determined at half-hour intervals during the day by the use of a sling psychrometer of a type approved by the U. S. Weather Bureau. The barometer readings were recorded at the same time, since altitude and atmospheric pressure likewise have an influence on the nature of the light and its consequent effects. It was thought this information might be helpful in comparing results obtained elsewhere.

Removal of Exposed Specimens. At the end of the first 25 hours of exposure and each successive 25 hours, specimens were cut according to the hours with which they were marked, removed from the beaver boards, and stored in the dark until the time of testing.

ULTRA-VIOLET RADIATION IN SUNLIGHT

The importance of ultra-violet radiation in the tendering of cellulose and in fading of certain dyes suggested that the quantity of this radiation occurring in the sunlight to which these fabrics were exposed, be determined.

The quantity of ultra-violet radiation in the sunlight at College Station was measured for a period of five weeks during the summer of 1931, and the results compared with measurements made elsewhere. Although the fabrics herein discussed were exposed the two preceding summers it was thought the sunlight of these years probably did not differ greatly in ultra-violet content. However, if we assume the sun spot theory to be correct the ultra-violet was probably greater during the exposure period than in 1931 (22).

Anderson and Robinson (2) devised an oxalic acid-uranyl sulphate method which they found sensitive throughout the range of ultra-violet emitted by a quartz mercury arc, and to the ultra-violet alone. This method, as developed by Tonney et al (49) for use in sunlight, was used in this study. Quartz petri dishes were used instead of a quartz cell. The following two stock solutions were prepared:

1. Exactly 6.2 grams of pure tested oxalic acid crystals and 4.27 grams of uranyl sulphate dissolved in distilled water and diluted to exactly one liter.
2. An approximately 0.1 N solution of potassium permanganate to be standardized against the oxalic acid solution (about 3.16 grams per liter).

To employ the depth of 1.5-2.0 centimeters advised by Anderson and Robinson (2), 31.5 cc. of oxalic acid-uranyl sulphate solution were placed in each of three quartz petri dishes. These were exposed in direct sunlight for exactly ten minutes on the roof of the same three-story building where the fabrics were exposed. The exposed solutions were emptied into beakers and the dishes washed twice with distilled water. After adding 2 or 3 cc. of concentrated sulphuric acid to each beaker, the solution was brought to a boil and titrated while hot with the potassium permanganate solution to a permanent pink color. From the average of the three titrations were determined the milligrams of oxalic acid decomposed per square centimeter of exposed surface in one hour. An exposure period of ten minutes was chosen to keep the percentage of decomposition well under fifty per cent, since a decomposition of more than fifty per cent causes the amount decomposed in each interval of time to become slightly less than it should have been (2).

Table 9 gives all determinations made at College Station.

Table 9. Ultra-violet measurements for College Station (1931) (expressed in mg. oxalic acid decomposed per sq. cm. in one hour)

Date	9:00-10:00	11:00-12:00	1:00-2:00	3:00-4:00	Maximum for day	Average for day
July 27	10.81	9.20	---- ----	---- ----	10.81	---- ----
July 28	8.09	4.74	6.00	8.21	8.21	6.76
July 29	8.00	6.11	---- ----	---- ----	8.00	---- ----
July average	8.97	6.68	---- ----	---- ----	9.01	---- ----
August 3	6.38	8.47	7.84	5.69	8.47	7.10
August 4	9.51	7.84	9.14	---- ----	9.51	---- ----
August 5	Cloudy	---- ----	6.26	10.07	10.07	---- ----
August 6	8.26	9.80	10.43	6.05	10.43	8.63
August 7	9.03	9.72	7.70	5.68	9.72	8.03
August 10	7.55	9.02	6.66	9.21	9.21	8.11
August 11	9.11	8.55	8.55	8.52	9.11	8.68
August 12	8.05	9.74	8.90	9.56	9.74	9.06
August 13	8.15	9.14	9.42	8.62	9.42	8.83
August 14	7.02	9.27	10.12	8.90	10.12	8.82
August 17	6.74	8.52	7.11	7.02	8.52	7.35
August 18	5.33	Cloudy	---- ----	---- ----	---- ----	---- ----
August 19	7.96	10.21	9.27	9.84	10.21	9.32
August 21	8.00	8.11	9.09	5.61	9.09	7.70
August 24	8.54	6.69	8.43	8.87	8.87	8.13
August 25	7.59	8.31	8.90	10.22	10.22	8.75
August 26	8.36	7.92	8.25	7.26	8.36	7.95
August 28	3.76	8.03	10.43	7.59	10.43	7.45
August ave.	7.61	8.71	8.62	8.04	9.50	8.24
August maximum	9.51	10.21	10.43	10.22	10.43	10.09
August minimum	3.76	6.69	6.26	5.61	8.36	5.58

The same method of determining the quantity of ultra-violet radiation in the sunlight has been reported for Denton, Texas (21), Chicago (49), Honolulu (22) (35), and San Juan, Porto Rico (25). Although the technique used varied somewhat and the seasons of the year were not identical, certain comparisons may be made.

The maximum decomposition occurring within a period of sixteen months as reported in the Chicago study was 7.12 mg. on July 8, 1927. The maximum decomposition during a period of two and a half years in Honolulu was 3.17 mg.[1] The maximum for a period of five and one-half months in San Juan was 9.47 (corrected according to author's instructions), approximately one-third that of Honolulu[2].

When the maxima in these regions are compared with the maximum decomposition of 10.81 mg. at College Station, it is noted that the ultra-violet radiation in the sunlight at Honolulu was less than one-third as great, that the Chicago radiation was approximately two-thirds as much,

[1]A personal communication from Lois Godfrey verifies these figures.
[2]A personal communication from Luis G. Hernandez corrects the statement in the original paper that the maximum "corresponds closely" to that of Honolulu.

and the San Juan radiation slightly less than that at College Station. If it is assumed that the ultra-violet radiation of the sunlight is approximately the same at College Station and Denton, College Station sunlight undoubtedly contains more ultra-violet radiation in the spring months than does Chicago for the same months.

The average hourly and maximum hourly readings at Denton, Chicago, San Juan, and College Station are shown in Figures 3 and 4.

The curve for College Station is straighter than the curves for the other regions, showing the ultra-violet content to be comparatively higher in the morning and late afternoon than at Chicago or San Juan. This indicates a more uniform daily ultra-violet radiation and a greater total radiation at College Station than in these other regions.

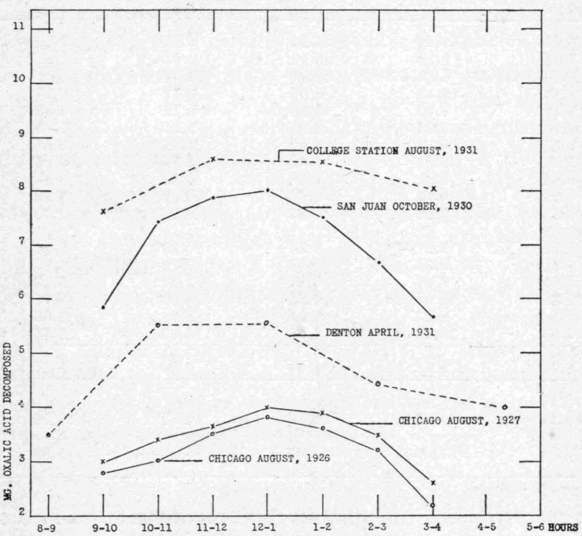


Fig. 3. Ultra-violet radiation. Average hourly readings.

The maximum decomposition measured at College Station occurred late in July when the sun's rays were less direct than earlier in the summer. Had the radiation been measured earlier in the season a higher maximum decomposition would probably have been obtained. Had the ultra-violet radiation been measured at College Station throughout an entire year, undoubtedly the comparatively long, dry, and sunny summer and short winter would have shown the yearly radiation at College Station to greatly exceed that at Chicago. Less seasonal variation at San Juan might be expected to give a total yearly ultra-violet radiation greater than at College Station.

From this study it is concluded that a higher maximum ultra-violet radiation of sunlight probably occurs at College Station during the summer than at any one season at San Juan. However, the total fading and tendering for the year may be greater at San Juan than at College Station. The tendering and fading due to College Station sunlight must be greater than that caused by the sunlight in Chicago or Honolulu.

THE EFFECT OF SUNLIGHT UPON COTTON CELLULOSE AS MEASURED BY COPPER NUMBER

The extent to which the cellulose of cotton has degraded during exposure to sunlight may be indicated by the reducing action of the degradation products on Fehling's solution (41). This measurement is called the copper number and is the amount of copper expressed in grams which can be reduced from the cupric to the cuprous state by one hundred grams of the cellulose under strictly defined conditions.

The copper number was determined for each of the 22 fabrics before and after definite periods of exposure. The Hagglund method as given by Hall (23) was used, all determinations being made either in duplicate or triplicate.

The results are shown in Table 10.

It is noted the copper numbers do not make smooth curves. There is in general an increase until after approximately 200 hours of exposure, where there is a decrease until 375 hours, when the numbers increase slightly. This lowering of copper number is not accompanied by a decrease in the loss in strength. This variation is probably due to the different steps in chemical reactions taking place during the oxidation of the cellulose. The actual chemical reactions are not known. Birtwell, Clibbens, Geake, and Ridge (8) believe that at least two consecutive reactions take place, the first oxidation product having an aldehydic character, which gives the copper number, while the oxidation of this aldehydic product in the second reaction causes it to lose its reducing property and to acquire acidic properties characterized by high methylene blue absorption. This theory explains why they found the copper number to increase until it reached a maximum where it continued for a time and then gradually decreased.

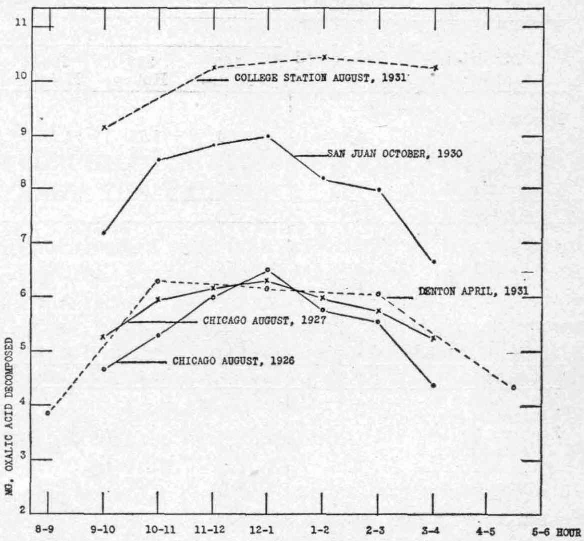


Fig. 4. Ultra-violet radiation. Maximum hourly readings.

Davidson (20) thinks it probable, from measurements of the oxygen absorption of cotton impregnated with sodium hydroxide of varying concentrations, that more than two consecutive reactions take place and that the various reactions are not single reactions, but each may consist of two or more side reactions. He found also that the rate of oxygen absorption increased rapidly at first, became constant and remained comparatively constant for some time, and then gradually decreased. He attributes these changes in rate to the successive reactions, the first oxidizing the cellulose,

Table 10. Copper numbers showing the effect of different periods of exposure to sunlight upon the cellulose of the fabrics

Material	Unexposed	Exposed					
		100 Hours	200 Hours	300 Hours	350 Hours	375 Hours	Average
Muslins:							
Hope	0.38	1.36	1.78	1.20	1.14	2.50	1.36
Lonsdale	0.49	1.90	2.22	1.30	1.22	2.52	1.60
Lockwood	0.13	0.81	0.86	1.26	0.45	1.73	0.87
Puget Sound	0.35	0.97	0.93	0.95	0.62	0.39	0.70
Average	0.34	1.26	1.45	1.18	0.86	1.79	1.13
Voiles:							
White	0.28	1.57	3.94	0.97	----	0.64	1.48
Blue	0.74	2.25	1.90	1.92	2.96	2.26	2.00
Green	0.75	1.93	4.33	2.03	----	1.55	2.12
Yellow	0.56	1.86	2.60	1.85	----	1.63	1.70
Lavender	0.57	2.93	2.78	2.09	----	1.73	2.02
Pink	0.16	1.34	1.91	1.70	----	1.34	1.29
Average	0.50	1.98	2.91	1.76	----	1.53	1.77
Yearround Zephyr:							
White	0.23	1.02	1.40	1.51	1.01	1.16	1.05
Blue	0.31	1.16	1.13	2.24	0.87	1.63	1.22
Green	0.31	2.10	1.37	1.91	0.99	1.72	1.40
Yellow	0.18	1.27	1.30	2.58	1.63	2.27	1.54
Lavender	0.15	1.26	1.27	2.38	1.64	1.60	1.38
Pink	0.39	1.35	2.10	2.68	1.47	2.12	1.68
Average	0.26	1.36	1.43	2.22	1.27	1.75	1.38
Pamico Cloth:							
White	0.19	2.39	2.32	1.52	0.86	1.24	1.42
Blue	0.56	0.95	1.11	1.40	1.08	1.24	1.06
Green	0.13	0.90	1.15	1.26	0.91	0.93	0.88
Yellow	0.16	1.90	1.72	1.65	1.40	2.30	1.52
Lavender	0.18	0.98	1.05	1.52	1.12	1.29	1.02
Pink	0.20	1.14	1.42	1.65	1.08	1.61	1.18
Average	0.24	1.38	1.46	1.50	1.08	1.44	1.18
Total average	0.34	1.52	1.85	1.71	1.20	1.61	

the second oxidizing the product of the first at a more rapid rate with the decrease in rate caused by the gradual decrease of the active mass of cellulose.

If we assume these theories to be correct, the higher copper numbers may have been due to the formation of the aldehydic or ketonic groups which reduce the Fehling's solution while the lower copper numbers were due to a proportionate increase in carboxyl groups, which do not reduce Fehling's solution. Had the methylene blue absorption been determined simultaneously this assumption might have been verified. Neither the losses in strength after 375 hours of exposure nor the copper numbers indicate that the rate of oxygen absorption has yet begun to decrease; however, measurements after longer exposures must be made to verify this assumption.

Davidson (20) found that even the small amount of iron present in the cotton fiber itself and in the sodium hydroxide caused an increase in the absorption of oxygen. Copper and nickel also had accelerating effects approximately equal, but less than iron. Manganese greatly retarded the oxidation of the cellulose impregnated with 0.5 N sodium hydroxide but the retarding effect became less and less as the concentration was increased. With a 10.3 N solution the reaction was at first slower but ultimately became faster until at 12.2 N there was a slight accelerating effect.

THE EFFECT OF EXPOSURE TO SUNLIGHT ON THE STRENGTH OF THE FABRICS

The strength of cotton fabrics when exposed to sunlight may be influenced by the nature of the dye, finish, size, the structure of the yarn and fabric, and the environmental factors. The change in the breaking strength of the fabrics due to these factors was expressed for each exposure period as a percentage loss from the original strength. These data are given in Tables 11 and 12 and summarized in Table 13 and in Figure 5.

Effect of Bleach, Finish and Size

Bleach. The Hope and the Lonsdale bleached muslins suffered a greater loss in strength than did the Lockwood and the Puget Sound unbleached muslins, as shown in Table 11. At the end of 75 hours of exposure, with the exception of the Lockwood filling, all muslins had lost ten to twenty per cent of their original strength. At the end of 250 hours all muslins except the filling of the Lockwood had lost from approximately one-fifth to one-third of their original strength. At the end of 375 hours of exposure the loss was from one-fifth in the Lockwood muslin to one-half in the Lonsdale filling. The total average loss of the unbleached muslins for the fifteen exposure periods was three-fifths as much as the loss of the bleached muslins, as shown in Table 11. It is evident that bleaching increases to a considerable extent the susceptibility of cotton fabrics to tendering.

The changes in color and strength, particularly the loss in strength, in the unbleached muslins, which most resemble raw cotton, suggest that similar changes may take place in cotton in the field. Studies now in progress will determine the extent of these changes and whether more frequent pickings are advisable.

Finish and Size. The greater tendering of the unbleached muslin warps over that of the fillings of the same fabrics may have been due to the kind and amount of size used in the warp yarns. The warps contained much more total size than did the fillings, as shown in Table 5. The sizes used for the warp threads may have included one or more substances which had a tendering effect when exposed to sunlight.

The colored voiles contained more total size and finish than the white voile and were also more tendered. A portion of this tendering may have been due to the kind and amount of size used in their manufacture.

The bleached muslins were not mercerized but the white voile, zephyr, and Pamico cloth were bleached and mercerized. The bleached muslins lost an average of 56 per cent of their original strength compared with an average loss of 33 per cent in the white mercerized fabrics. This indicates that mercerization decreases the tendering of cotton.

Table 11. Muslins: Percentage loss in breaking strength of fabric due to exposure to sunlight for the 15 twenty-five-hour periods

	Bleached muslin				Unbleached muslin			
	Hope		Lonsdale		Lockwood		Puget Sound	
Hours of exposure	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
25	6.12	10.69	6.88	7.35	4.38	0.05	3.98	10.93
50	7.56	10.75	11.96	7.89	11.36	3.87	12.25	12.92
75	10.36	16.85	19.20	18.40	10.63	7.19	14.83	15.19
100	18.02	20.27	22.71	29.81	14.78	15.15	16.40	19.13
125	22.55	17.47	27.03	26.76	16.78	11.17	19.15	16.69
150	22.50	18.58	25.84	23.21	14.76	7.88	16.28	15.26
175	25.85	23.65	34.91	33.00	16.15	10.23	20.67	16.54
200	27.41	28.54	35.96	38.33	19.45	13.14	22.51	18.77
225	30.87	26.82	36.60	28.56	16.98	9.30	21.81	16.95
250	33.18	25.42	32.07	32.32	20.15	16.41	25.17	19.05
275	25.03	31.44	38.16	36.61	28.12	11.70	29.24	16.86
300	24.90	33.99	40.70	45.28	31.05	15.36	26.83	18.54
325	34.94	40.24	30.59	54.12	23.86	22.79	23.67	21.01
350	39.88	43.64	36.54	55.97	24.81	17.96	24.89	20.80
375	41.59	43.71	41.11	51.18	21.03	20.64	26.36	21.76
Av.	24.71	26.13	29.35	32.59	18.28	12.19	20.26	17.36

Effect of Dyes on Tendering

Vat Dyes. Dyestuffs are usually classified according to their chemical nature and reaction towards the fiber. The vat dyestuffs themselves are insoluble and must be first reduced by some strong reducing agent such as sodium hydrosulphite, and then dissolved in an alkaline liquor. This combination is the so-called "vat", and dyes used in this manner are called vat dyes. These dyes are much used on cotton and as a class are characterized by great fastness (36).

Information concerning the dyes used in these fabrics is given in Table 14. The zephyrs and Pamico cloths were dyed with vat dyes. As shown in Table 13 and Figure 5 the white zephyr and Pamico were tendered more than the colored zephyrs and Pamicos with the exception of the yellow zephyr. This indicates that with the exception of the yellow dye of the zephyr, the vat dyes afforded some protection against the tendering action of sunlight. The particular Indanthrene dye used in the yellow zephyr is not known but since the greatest loss in strength among the vat-dyed fabrics occurred in this fabric, it is evident it was one of the yellow vat dyes known to have a tendering effect. The yellow Pamico which was

Table 12. Percentage loss in breaking strength of fabric due to exposure to sunlight for the 15 twenty-five-hour periods

Hours of exposure	White		Blue		Green		Yellow		Lavender		Pink	
Year-round Zephyr	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
25	+7.11	7.23	1.51	2.79	+3.37	2.79	0.42	7.49	0.99	0.52	+4.25	0.07
50	3.54	6.67	+1.87	+8.60	+3.59	4.20	+2.87	10.63	5.87	2.42	+1.56	0.65
75	7.25	8.15	+1.29	+11.15	6.02	7.61	4.55	22.93	2.00	7.38	0.89	2.46
100	1.61	13.74	1.49	+2.55	3.25	6.69	5.88	18.39	5.67	10.40	+2.04	3.09
125	3.44	22.01	+0.13	2.51	+0.81	1.89	14.13	37.12	11.09	4.98	2.96	7.70
150	16.24	16.28	2.44	5.46	13.17	+2.21	13.29	18.85	9.46	4.92	10.45	19.50
175	16.65	21.84	2.11	9.69	8.41	1.34	10.34	21.42	13.48	9.51	7.32	17.84
200	17.58	25.58	0.33	13.90	8.17	4.20	12.21	33.79	16.66	18.80	14.39	18.22
225	19.56	16.48	6.52	4.87	14.83	16.57	17.74	29.31	12.82	18.06	14.62	19.37
250	23.17	16.49	6.26	8.28	9.01	15.99	16.19	23.82	13.05	19.49	9.92	21.16
275	10.88	26.31	2.59	16.63	8.65	21.38	13.81	22.80	17.72	19.37	6.45	18.24
300	12.56	16.75	0.99	17.23	3.08	19.95	20.88	29.04	11.18	21.99	9.08	23.42
325	21.47	32.39	11.46	18.77	10.70	23.59	23.76	37.65	26.82	25.46	11.80	29.82
350	22.71	25.99	12.66	14.45	12.22	41.46	24.04	32.13	21.64	29.35	17.79	31.88
375	24.00	32.72	13.33	10.54	7.85	32.39	28.35	52.33	28.49	42.30	23.18	35.78
Av.	12.90	19.24	3.89	6.85	6.51	13.18	13.51	26.51	13.13	15.66	8.07	16.61
Pamico Cloth												
25	5.39	4.67	+2.57	1.44	3.18	3.70	+1.18	11.88	3.19	1.87	+0.37	+0.62
50	5.81	5.11	+7.20	+2.44	+1.22	3.26	0.48	2.69	4.19	7.46	0.41	+0.04
75	10.44	15.00	+4.60	11.30	2.10	11.42	3.26	10.27	+0.31	9.52	3.46	9.80
100	10.85	19.45	+3.14	5.37	+2.02	13.25	6.59	20.88	6.05	16.42	4.32	14.88
125	11.58	30.51	+0.91	18.17	2.29	5.60	7.84	12.15	+4.52	13.61	7.25	17.60
150	15.72	23.84	2.51	18.83	7.69	9.92	13.58	3.73	+0.46	12.71	7.50	20.52
175	15.77	28.74	3.39	23.49	7.56	20.60	11.28	14.95	0.68	14.43	8.28	27.18
200	20.70	29.16	7.76	20.41	8.29	20.11	13.37	13.26	+0.08	14.80	11.06	28.77
225	20.70	23.44	11.75	11.95	9.79	15.78	13.80	14.20	2.92	11.68	12.37	22.36
250	21.57	14.70	5.95	10.54	12.73	5.34	17.44	15.33	8.71	10.54	15.96	22.44
275	21.12	22.19	2.39	21.21	0.44	10.53	19.01	14.81	5.18	12.06	11.40	28.31
300	20.39	19.57	0.37	16.76	11.00	17.48	16.76	19.84	6.26	18.36	15.73	25.19
325	25.57	34.41	10.10	20.52	9.89	27.75	23.50	20.23	7.49	34.01	11.59	41.10
350	28.24	33.34	8.27	21.25	10.37	34.10	27.49	16.65	5.59	32.57	16.53	39.08
375	32.11	27.58	10.08	21.49	17.44	29.08	33.50	22.17	10.13	33.39	18.51	36.99
Av.	17.73	22.11	2.94	14.69	6.64	15.19	13.78	14.20	3.67	16.23	9.60	22.24
Voiles												
25	0.17	+4.18	12.18	5.79	8.16	3.27	2.06	1.41	4.83	+2.27	5.53	+0.30
50	+0.52	+0.46	19.59	26.79	8.28	8.21	6.92	1.16	7.09	5.89	4.67	0.60
75	1.72	0.96	33.98	23.47	12.11	15.25	9.81	10.91	11.64	7.40	8.82	0.26
100	2.27	1.65	26.48	34.48	16.02	18.64	9.80	18.25	14.83	10.39	7.81	6.77
125	4.84	10.58	30.74	24.16	18.20	19.48	15.85	17.91	17.15	6.80	10.09	10.00
150	7.53	12.29	35.02	39.01	20.54	23.97	15.36	19.41	16.68	10.12	14.74	14.39
175	12.54	12.29	22.56	28.82	23.05	19.45	17.67	20.91	19.91	20.25	11.07	12.28
200	10.26	14.99	18.50	28.18	24.19	25.45	21.29	26.08	23.11	23.03	12.97	13.18
225	15.62	15.20	26.59	25.92	24.74	21.48	21.38	23.59	23.31	25.84	20.85	14.41
250	12.75	8.83	26.91	25.78	27.89	22.22	22.81	26.73	23.55	23.71	25.98	16.67
275	12.64	14.25	29.01	28.92	22.23	30.37	20.09	29.37	24.70	28.54	22.51	23.13
300	13.41	22.43	30.96	43.91	24.80	26.66	28.12	41.20	26.30	21.57	18.65	28.87
325	24.21	33.59	32.33	42.01	37.94	40.71	40.81	37.99	38.06	45.99	21.21	48.69
350	26.51	36.33	34.75	40.53	35.35	36.11	39.58	41.01	40.72	52.86	21.74	47.20
375	27.79	42.32	39.03	44.07	39.45	45.84	37.16	39.63	43.73	53.34	26.81	52.35
Av.	11.45	14.74	27.91	30.79	22.86	23.81	20.58	23.70	22.37	22.23	15.56	19.23

dyed with ½ per cent Carbanthrene Yellow G Double Paste was not tendered as much as the yellow zephyr but more than any of the dyed Pamicos, with the exception of the pink. This suggests that this yellow dye may also be one of the yellow vat dyes which cause tendering.

Table 13. Summary by fabric, color, and yarn of the average percentage loss in breaking strength of fabric due to exposure to sunlight during 15 exposure periods

Color	Yearround Zephyr		Pamico Cloth		Voiles		Bleached Muslins		Unbleached Muslins	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
White	12.90	19.24	17.73	22.11	11.45	14.74				
Blue	3.89	6.85	2.94	14.69	27.91	30.79				
Green	6.51	13.19	6.64	15.19	22.86	23.81				
Yellow	13.51	26.51	13.78	14.20	20.58	23.70				
Lavender	13.13	15.66	3.67	16.23	22.37	22.23	[1]24.71	26.13	[3]18.28	12.19
Pink	8.07	16.61	9.60	22.24	15.56	19.23	[2]29.35	32.59	[4]20.26	17.36
Average	9.67	16.34	9.06	17.44	20.12	22.42	27.03	29.36	19.27	14.77

[1]Hope
[2]Lonsdale
[3]Lockwood
[4]Puget Sound

The blue zephyr and Pamico were less tendered than any of the other fabrics. The warps of the blue zephyr and Pamico lost very little strength under 300 hours and the filling showed little change in strength before 125 hours of exposure. This corroborates the theory that many blue vat dyes protect fabrics from the tendering action of light. Ranked in order of their resistance to tendering the vat dyes are blue, green, lavender, pink, and yellow. This order indicates that the colors absorbing

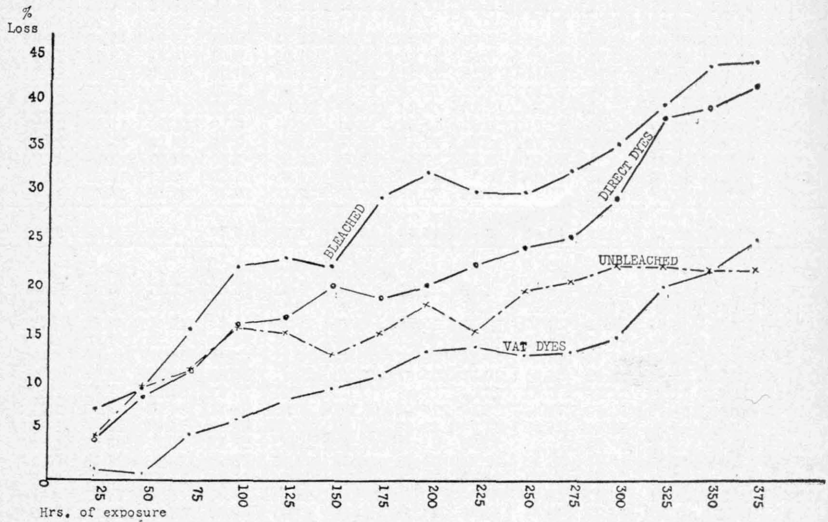


Fig. 5. Loss in breaking strength of unbleached and bleached fabrics and fabrics dyed with vat and direct dyes.

the shorter wave lengths which are thought to have the greatest tendering effect, cause greater tendering than those reflecting these same wave lengths, as has been suggested by various workers (6) (34).

The darker colors have in general shown greater resistance to tendering than the lighter colors and much more than the white. This may be due to the fact that the dark colors admitted fewer of the short wave lengths which cause tendering than did the light colors.

Irregularities in the rate of tendering occurred in all fabrics. Therefore differences in rate of tendering are evidently not due to the dyes.

Direct Dyes. The class of dyestuffs called direct or substantive includes those dyes which may be applied directly to the fabric without previous reducing or after developing. These dyes are usually applied to cotton in an alkaline bath containing either sodium chloride or sodium sulphate. These salts increase the exhaustion of the dye bath and the penetration of the color through the fiber (36). As a class they are considered less fast than vat dyes.

The voiles were dyed with direct dyes. They were tendered more with the exception of the pink voile than was any fabric dyed with vat dyes. The greatest loss in strength among the voiles occurred in the blue, which also showed the greatest loss in color. Both the blue and yellow voiles contained Erie Yellow Y. The fact that the yellow was less tendered than the blue suggests that the Blue Niagara dye in the blue voile may have caused the tendering or that the tendering was due to the combination of dyes used. The least tendering occurred in the pink, the darkest of the voiles. The pink tendered less rapidly during the early periods of exposure than the other colored voiles. The average losses in strength of the green, yellow, and lavender voiles were approximately equal. These differences in tendering cannot be explained by the wave lengths absorbed but are doubtless due to the chemical nature of the dyes rather than the color.

From this study it may be concluded that vat dyes, with the exception of certain yellows, afforded protection while the direct dyes apparently accelerated the tendering action of sunlight.

The Effect of Structure on Tendering

Weave. All fabrics used in this study were woven with a plain weave; therefore differences in tendering cannot be attributed to differences in weave.

The voiles, because of their more open weave, with larger spaces between yarns, exposed a proportionally greater area of yarn surface to sunlight than did the other fabrics, a structural factor which is thought to increase tendering.

Thickness and Weight. The Pamicos are the thickest of the fabrics as well as the heaviest. Thus they offer more resistance to penetration of light than thinner, lighter weight fabrics. The muslins are second in weight and thickness followed by the zephyrs and voiles. The zephyrs are

Table 14. Finish, dyes, and guarantees of fabrics[1]

Fabric	Bleach	Mercerization	Class and name of dye	Guarantee
Yearround Zephyr				Refund cost of material plus cost of trimming and making. Guaranteed "fast to sunlight, washing, perspiration and durability". Must pass "Nafal" test (exposure in Fade-Ometer for 24 hours with no preceptible fading.)
White	Chlorine	Yes		
Blue	"	"	Indanthrene dyes	
Green	"	"		
Yellow	"	"		
Lavender	"	"		
Pink	"	"		
Pamico Cloth[2]				"Money back"
White	Soda Chemic	Yes	2¼ % Carbanthrene Blue B.C.S. Double Paste Nat'l Aniline Co.	
Blue	"	"	¼ % Ponsol Violet A. R. Paste, Dupont Co.	
Green	"	"	3½ % Anthrene Jade Green Paste, Newport Co.	
Yellow	"	"	½ % Carbanthrene Yellow G. Double Paste, Nat'l. Aniline Co.	
Lavender	"	"	1½ % Anthrene Violet B. N. Extra Paste, Newport Co.	
Pink	"	"	2% Ponsol Red B. N. Double Paste, Dupont, Co.	
Voiles				"No guarantee on dyes"
White	Liquid chlorine gas	Yes	Pad dyed with:	
Blue	"	"	Niagara Blue 6 B and Erie Yellow Y	
Green	"	"	Erie Green M. T. and Pontamine Yellow 5 G. L.	
Yellow	"	"	Erie Yellow Y and Pontamine Orange S.	
Lavender	"	"	Chlorantine Violet 5 B. L. and Pontamine Red 8 B. L.	
Pink	"	"	Pontamine Scarlet 4 B. S. and Pontamine Red 8 B. L.	
Muslins	Bleached			
Hope	Method not given	No		
Lonsdale	"	"		
Lockwood	Unbleached	"		
Puget Sd.	"	"		

[1]This information was given by and printed with the consent of the manufacturer or dyer.

[2]Manufacturers of Pamico Cloths state dyeings were made on all shades with caustic soda and hydrosulphite by the jig dying process, except blue, which was dyed by pad and jig method, the color being padded on along with some gum arabic in the unreduced condition, dried, transferred to jig, then dyed with usual amount of caustic and hydrosulphite. Goods were rinsed slightly, oxidized with sodium bichromate and acetic acid except the blue, which was oxidized with sodium perborate. After oxidizing, the fabrics were rope soaped for 20 minutes.

heavier than the voiles but of approximately the same thickness. These differences in thickness and weight may have had a slight influence on the relative tendering of the various fabrics. It is noted that the thicker, heavier fabrics were less tendered than the light voiles.

Yarn. All fabrics, with the exceptions of the unbleached muslins and lavender voile, were tendered more in the filling than in the warp yarns. The greater percentage crimp of the filling yarns over that of the warp caused more of the filling to appear on the surface of the fabric with a consequent protection from the light of the warps lying beneath them. This was probably one cause of the greater tendering of the filling over the warp.

The zephyrs and muslins are both composed of single ply yarns which have approximately the same twist-constants; therefore differences in their tendering cannot be attributed to differences in ply or twist.

The Pamicos and colored voiles are composed of two-ply yarns. The twist-constants are higher in the voiles and the resulting tighter twist should have caused them to resist tendering slightly more than the Pamicos, according to the findings of Cunliffe and Farrow (19). The white voile is composed of single yarns while the colored voiles are of doubles. Since single yarns have been found more resistant to tendering than doubles of the same weight, the structure of the white voiles as well as the dyes may have been a cause of the difference between the tendering of the white and the colored voiles. When comparisons are made between the white zephyr and voile, and the white Pamico, all of which are bleached and mercerized, it is noted that the Pamico was much more tendered than the voile and somewhat more than the zephyr. This also suggests that singles are more resistant to tendering than doubles.

These findings agree in general with those of Cunliffe and Farrow (19), who concluded that greater resistance to tendering by light was found in coarse, hard twisted yarns than in fine, soft twisted yarns; that tendering of mercerized fabrics was slightly less than unmercerized; gray yarns were less tendered than bleached; and that double yarns were weaker than singles of the same weight.

It is evident from these conclusions that the cloth most resistant to tendering by light should be composed of mercerized, coarse, gray, hard twisted single yarns.

Analysis by Correlation of Factors Influencing Tendering

The structure of the yarns and fabrics and conditions of exposure are known to influence the tendering of cotton fabrics when exposed to sunlight. These factors were subjected to correlation analysis to see what relationship such treatment might show. The structural factors included in this analysis were thread count, ply, take-up, crimp, yarn size, and twist. It was hoped thus to learn, from the relationships indicated by the correlation coefficients, the part each factor played in the tendering of the fabric and to place it in the order of its importance with the remaining factors.

The breaking strength for each period of exposure was expressed as the percentage loss from the original strength. These data were smoothed to remove random and irregular fluctuations, by choosing from three types of logarithmic curves and a group average, the one best fitting the data. The readings from the fitted curves were used in the correlation calculations instead of the original observations. The original data from which the adjusted figures were derived are given in Tables 11 and 12.

Structural Factors. In measuring the effect of the structural factors on tendering, the average percentage loss in strength for the entire fifteen exposure periods as derived from the fitted curves was used. The structural factors used are given in Tables 2 and 3.

After adjusting for the number of observations and variables a multiple correlation coefficient of 0.52 ± 0.072 was found between breaking strength and the structural factors. When this coefficient is converted into a coefficient of determination and read as percentage it is found that 27 per cent of the change in breaking strength may be accounted for by the structure of the yarns and fabrics.

Part correlation coefficients showing the relation between breaking strength and these factors were determined.[1] Ranked in order of their importance they are:

Percentage take-up	0.69
Ply	0.48
Yarn size	0.10
Percentage crimp	0.10
Threads per inch	0.02
Twists per inch	0.02

It is noted that percentage take-up and ply together account for most of the change caused by the factors inherent in the fabrics, with take-up accounting for more of the change than ply. Yarn size, crimp, thread count, and twists do not have significant coefficients. They account for little of the loss in strength due to this group of factors. From these coefficients it seems the tension of the twist is of more importance than the number of turns per inch. If these coefficients give a true measure of the effect of each of these factors, it is evident crimp was not the cause of the comparatively greater change in strength in the filling yarns, since according to this analysis it accounted for only one per cent of the change.

The Effect of Atmospheric Conditions on Tendering

Conditions of Exposure. Correlation analysis was used to measure the effect of the hours of exposure, temperature, and relative humidity upon the change in the breaking strength of the fabrics.

[1]Ezekiel, Mordecai, 1930. Methods of correlation analysis. 181-185, 379-380, John Wiley & Sons. Part correlation differs from the more commonly used partial correlation in that all the original variation in the independent factor is left in it and only the dependent factor is adjusted while the partial correlation measures the variation of the dependent and one independent variable with the influence of the other independent variable removed from both.

The data for temperature and relative humidity which had been recorded at half-hour intervals throughout the exposure periods were averaged for each 25-hour period, using half hour or fraction thereof as a unit. These averages for each exposure period are given in Table 15.

Table 15. Average relative humidity and temperature of exposure periods of 25 hours each

Period	Number of hours	H. R. %	Temp °F	Dates	
1	25	53.20	81.74	May 22, 23, June 6, 7	1929
2	50	55.57	88.62	June 10, 11, 14, 18	1929
3	75	48.74	91.53	June 18, 20, 21, 24, July 8	1929
4	100	59.88	87.95	July 9, 10, 11, 12, 15	1929
5	125	53.44	91.08	July 16, 17, 18, 19	1929
6	150	52.14	90.83	July 23, 24, August 13, 14	1929
7	175	43.75	91.50	August 15, 16, 19, 20, 21	1929
8	200	46.25	92.11	August 22, 23, 26, 27	1929
9	225	41.77	89.20	August 29, Sept. 25, 26, 27	1929
10	250	41.14	84.44	Sept. 30, October 2, 3, 7	1929
11	275	52.34	82.68	October 14, 16, 17, 18	1929
12	300	27.88	69.85	October 22, 24, 25, 28	1929
13	325	51.41	91.07	July 3, 7, 8, 9	1930
14	350	45.38	95.98	July 9, 10, 14, 15	1930
15	375	45.80	91.65	July 15, 16, 17, 18, 21	1930

The changes in breaking strength of the warp and filling of each fabric for each of the fifteen exposure periods, as derived from the fitted curves, were used.

In all cases a significant coefficient of multiple correlation between loss in breaking strength and hours of exposure, relative humidity, and temperature was obtained. In 36 of the 44 cases (including both warp and filling of the 22 fabrics) the coefficients ranged from 0.93 to 0.99. In 5 cases the coefficients ranged from 0.84 to 0.89 while in three cases the coefficients were 0.72, 0.73, and 0.78, which were for green Yearround zephyr warp, blue voile warp, and blue Pamico filling, respectively. These three lower coefficients were due to the somewhat erratic behavior of these fabrics which, because of differences in dye, finish or structure, did not show as consistent loss in strength as the other fabrics, as shown in Table 12.

When these correlation coefficients were squared and thus converted into coefficients of determination and read as percentages, it was found that in 36 of the 44 cases, hours of exposure, temperature, and relative humidity accounted for 86 to 99 per cent of the loss in strength. In 5 cases they accounted for 70 to 85 per cent, while in the other 3 cases 52, 53, and 62 per cent of the loss was accounted for by these three factors.

The effects of each of the three factors were measured separately by the use of part correlations. These coefficients are given in Table 16.

From the part correlations it was found, as was expected, that the length of exposure had the greatest influence on change in strength. In 28 of the 44 cases the coefficients of part correlation ranged from 0.95 to 0.99, thus accounting for 90 to 99 per cent of the change in breaking strength. In 12 cases the coefficients ranged from 0.90 to 0.94 account-

Table 16. Coefficients showing the relation between breaking strength of the various fabrics and hours of exposure, temperature, and relative humidity

	Warp						Filling					
	Coefficient of part correlation			Beta coefficient[4]			Coefficient of part correlation			Beta coefficient		
	Hrs.Exp.[1]	R.H.[2]	Temp.[3]	Hrs.Exp.	R.H.	Temp.	Hrs.Exp.[1]	R.H.[2]	Temp.[3]	Hrs.Exp.	R.H.	Temp.
Yearround Zephyr:												
White	0.923	0.303	0.322	0.878	—.117	0.125	0.944	0.247	0.438	0.909	—.081	0.154
Blue	0.904	0.274	0.126	0.970	0.131	0.058	0.968	0.354	0.216	0.927	—.090	0.053
Green	0.670	0.361	0.229	0.625	—.268	0.163	0.907	0.371	0.274	0.998	0.185	—.132
Yellow	0.978	0.258	0.643	0.946	—.053	0.167	0.953	0.091	0.245	0.926	—.027	0.235
Lavender	0.999	0.332	0.239	1.005	0.009	—.006	0.966	0.241	0.180	1.002	0.067	0.049
Pink	0.980	0.317	0.628	0.941	—.067	0.155	0.994	0.164	0.449	0.984	—.018	—.054
Pamico Cloth:												
White	0.994	0.328	0.690	0.973	—.036	0.100	0.780	0.369	0.646	0.674	—.215	0.459
Blue	0.975	0.352	0.545	0.933	—.080	0.139	0.721	0.351	0.561	0.641	—.231	0.417
Green	0.951	0.382	0.211	0.899	—.120	0.063	0.989	0.264	0.390	1.009	0.040	0.073
Yellow	0.992	0.011	0.512	0.991	—.001	0.075	0.986	0.341	0.286	1.020	0.064	—.033
Lavender	0.904	0.374	0.485	0.984	0.187	—.258	0.935	0.239	0.408	0.969	0.095	0.164
Pink	0.975	0.367	0.218	0.936	—.084	0.048	0.993	0.275	0.555	0.974	—.034	0.087
Voiles:												
White	0.983	0.122	0.539	0.970	—.023	0.114	0.981	0.294	0.264	1.012	0.062	0.055
Blue	0.743	0.137	0.425	0.756	0.094	0.320	0.945	0.104	0.542	0.922	—.034	0.207
Green	0.971	0.210	0.738	0.927	—.049	0.249	0.962	0.031	0.555	0.963	0.009	0.181
Yellow	0.988	0.259	0.317	1.010	0.043	0.054	0.988	0.155	0.294	0.977	—.024	0.048
Lavender	0.978	0.160	0.471	0.992	0.035	0.114	0.972	0.344	0.039	1.020	0.090	0.010
Pink	0.990	0.110	0.033	0.964	—.052	0.014	0.967	0.343	0.192	1.016	0.098	0.053
Muslins:												
Hope	0.980	0.395	0.680	0.932	—.119	0.178	0.982	0.342	0.082	1.021	0.071	—.016
Lonsdale	0.909	0.142	0.042	0.956	0.022	0.018	0.989	0.105	0.453	0.997	0.016	0.074
Lockwood	0.923	0.303	0.322	0.940	—.117	0.125	0.927	0.044	0.202	0.931	0.016	0.078
Puget Sound	0.923	0.303	0.322	0.878	—.117	0.126	0.923	0.306	0.323	0.874	—.118	0.125

[1]Relative humidity and temperature held constant.
[2]Hours of exposure and temperature held constant.
[3]Hours of exposure and relative humidity held constant.
[4]Each variable stated in units of its own standard deviation.

ing for 81 to 89 per cent of the change in strength. In the other 4 cases the coefficients of part correlation were 0.77 for white Pamico filling, 0.74 for blue voile warp, 0.72 for blue Pamico filling, 0.67 for green zephyr warp, thus accounting for 60, 55, 52, and 49 per cent respectively of the change in strength. It is noted that the lower part correlation coefficients occur in the same fabrics as did the lower multiple correlation coefficients but not in the same relative positions.

The coefficients of part correlation for the temperature ranged from 0.62 to 0.73 in 6 cases, from 0.42 to 0.56 in 14 cases, from 0.20 to 0.40 in 17 cases, and from 0.04 to 0.19 in 7 cases. When these are compared as percentages it is found that in 6 cases temperature accounts for 38 to 53 per cent of the change in breaking strength, in 14 cases for 18 to 31 per cent, in 17 cases for 4 to 16 per cent, and in 7 cases for 0.16 to 3.6 per cent.

The part correlation coefficients show that relative humidity accounted for approximately half as much of the change in breaking strength as did the temperature. The coefficients of part correlation for humidity ranged from 0.01 to 0.39, with 31 cases falling above 0.20 and 13 cases falling below 0.20; of these 13 cases, 4 were below 0.1. In no case did relative humidity account for more than 16 per cent of the change in strength and in 4 cases for less than 1 per cent.

To place on a more comparable basis the effects of hours of exposure, temperature, and relative humidity on the breaking strength, and to determine the direction of these effects, the beta coefficients were determined as given in Table 16. With the exception of 6 of the 44 cases, the beta coefficients for temperature are positive, showing that in most cases an increase in temperature was accompanied by an increase in the loss in strength. The beta coefficients for relative humidity show a more nearly equal division of positive and negative signs, indicating that in some cases a loss in strength was accompanied by an increase in relative humidity, while in other cases the loss in strength was accompanied by a decrease in relative humidity. The smallness of these coefficients and the nearly equal division of signs indicate that the relative humidity had little effect upon the loss of strength when these fabrics were exposed to sunlight under natural conditions of temperature and humidity.

It is generally assumed that relative humidity has a greater influence on tendering than moderate temperature. This assumption has been based on studies which maintained, in many cases by artificial means, a much wider range of temperature and relative humidity than occurred under the natural exposure conditions included in the present study. The conditions under which the fabrics of this study were exposed included a range of only 26 degrees F. in temperature and 32 per cent in relative humidity. Had the natural conditions of exposure included a wider range of either temperature or relative humidity, or both, a different relationship might have been established by the use of correlation calculations.

It was found by correlation analysis that the hours of exposure had much greater effect on breaking strength than all other factors. Temperature had a greater effect on change in strength than did relative humidity, in most cases accounting for twice as much of the change as did the humidity. The correlation analysis in which were used the structural characteristics for the fabrics, shows that only two of these factors, percentage take-up and ply, had any material effect upon the change in strength occurring upon exposure to sunlight.

EFFECT OF EXPOSURE TO SUNLIGHT ON THE COLOR OF THE FABRICS

Spectrophotometric Analysis of the Fabrics

All fabrics underwent some change in color upon exposure as shown by spectrophotometric analysis. Not all changed in the same manner or to the same extent. Some colors became lighter; some became darker and then lighter; others showed a change in hue.

Unbleached Muslins. The unbleached muslins became lighter as the exposure period lengthened, the light bleaching the natural coloring matter left in the cotton fibers. At the end of the 375-hour period, although somewhat lighter, neither of the unbleached muslins was bleached. There was a greater change in the Lockwood muslin which had been slightly bleached during the process of manufacture, than in the unbleached Puget Sound muslin, as shown in Figures 6 and 7.

Bleached Muslins. The two bleached muslins became slightly lighter when exposed for 25 hours, as shown in the curves for Lonsdale muslin in Figure 8, but by the end of 50 hours they had begun to darken and continued to darken throughout the period, reflecting more toward the yellow end of the spectrum than at other wave lengths. The Lonsdale showed slightly more change than the Hope as given in Figure 9. The yellowing of these fabrics was probably due at least in part to the formation of oxycellulose, which increases the yellow color in cotton (41) (45).

White Fabrics. The bleached, mercerized, undyed fabrics all became darker, reflecting comparatively more toward the yellow and less toward the blue end of the spectrum. This gave them a yellowish-white hue. The white zephyr underwent more total color change than did the Pamico or voile. The voile showed a change in color at an earlier hour than did the zephyr or Pamico. This may have been due to the larger area of yarn exposed to the light in the open weave of the voile than was the case in the more closely woven zephyr and Pamico. The color curves for the white fabrics are given in Figures 10, 11, and 12.

Blue Fabrics. Of the three blue fabrics, the Pamico and zephyr dyed with vat dyes were a darker blue than the voile, dyed with direct dyes. The Pamico was dyed with a mixture of two vat dyes, as shown in Table 14. The dye used in the zephyr is not known. The voile was dyed with two direct dyes, one a yellow and the other a blue.

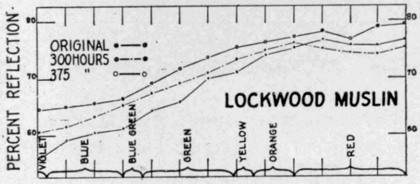


Fig. 6. Color curves for unexposed and exposed Lockwood muslin.

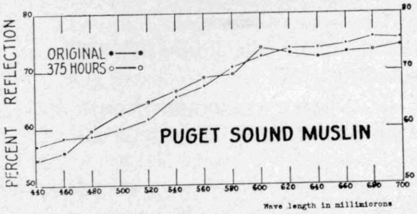


Fig. 7. Color curves for unexposed and exposed Puget Sound muslin.

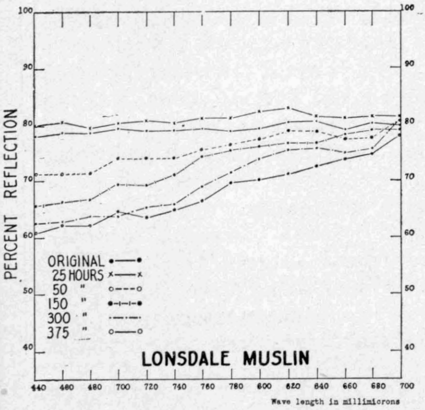


Fig. 8. Color curves for unexposed and exposed Lonsdale muslin.

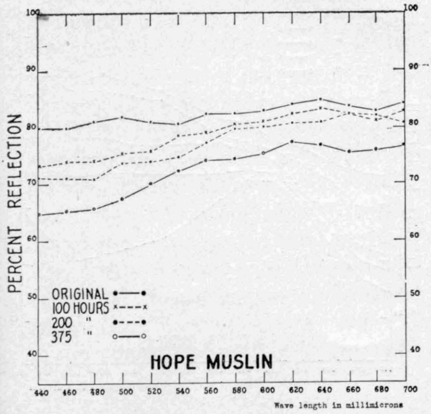


Fig. 9. Color curves for unexposed and exposed Hope muslin.

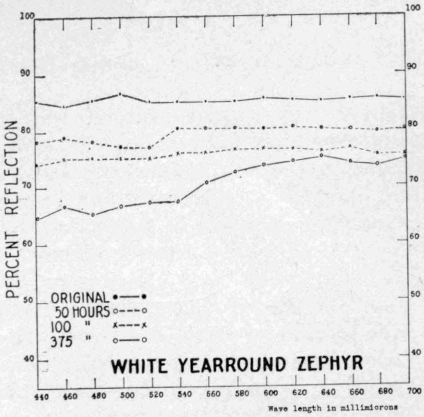


Fig. 10. Color curves for unexposed and exposed white Yearround zephyr.

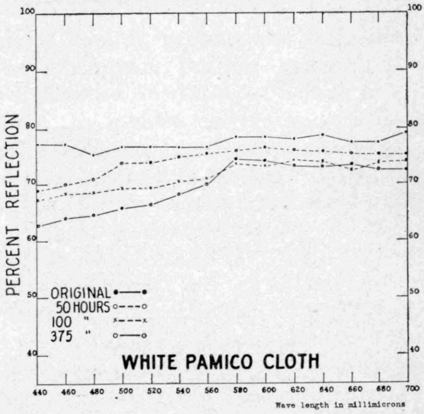


Fig. 11. Color curves for unexposed and exposed white Pamico cloth.

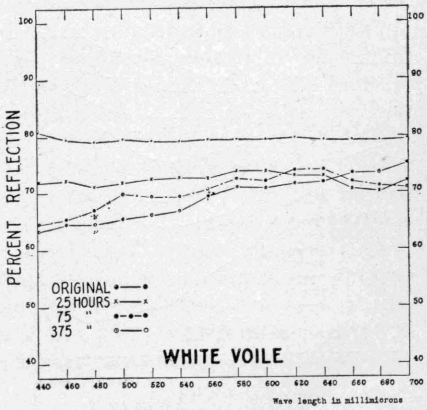


Fig. 12. Color curves for unexposed and exposed white voile.

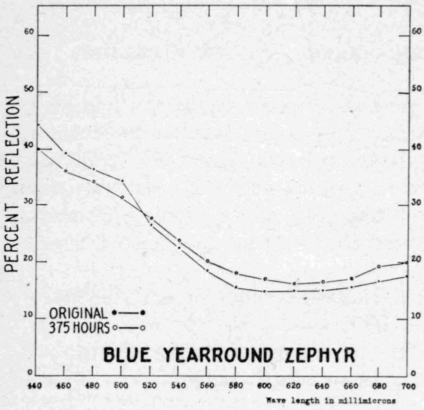


Fig. 13. Color curves for unexposed and exposed Yearround zephyr.

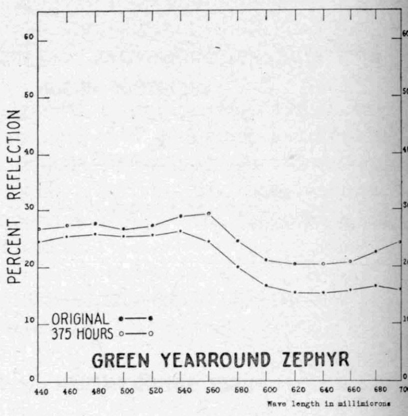


Fig. 16. Color curves for unexposed and exposed green Yearround zephyr.

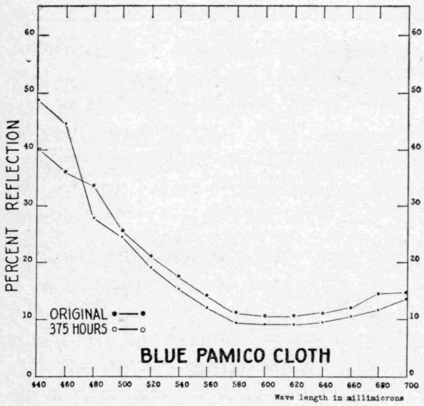


Fig. 14. Color curves for unexposed and exposed blue Pamico cloth.

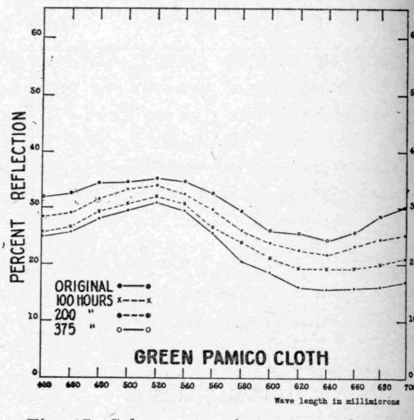
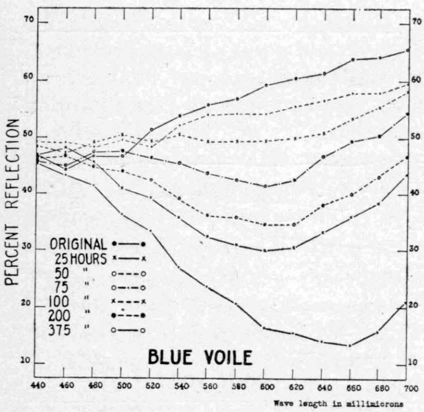


Fig. 17. Color curves for unexposed and exposed green Pamico cloth.



600 620 640 650

Fig. 15. Color curves for unexposed and exposed blue voile.

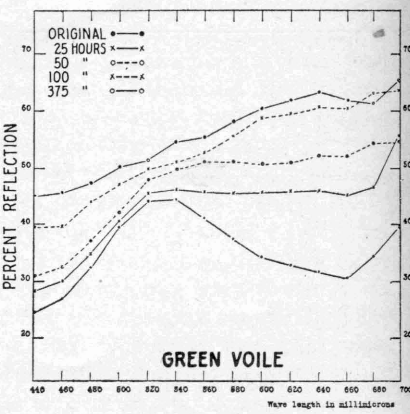


Fig. 18. Color curves for unexposed and exposed green voile.

From the spectrophotometric curves for the blue zephyr and Pamico, Figures 13 and 14, it is noted that little change in color occurred upon exposure. Both reflected slightly less in the blue end of the spectrum and slightly more beyond 470 millimicrons in the Pamico, and beyond 520 millimicrons in the zephyr. As shown by the curves of the original fabrics, the zephyr was a slightly lighter blue than the Pamico.

The blue voile shows a decided difference in its reaction to light exposure. Although no analysis was made of the color before 25 hours of exposure, fading was quite evident after one day's exposure. The greatest fading occurred during the first 25-hour period but the color change continued throughout the entire 375 hours of exposure, as shown in Figure 15. From the curves it is seen the fabric underwent considerable change in hue. From the light blue of the unexposed it became almost gray after 100 hours, and a grayish-yellow in which none of the original blue could be detected at the end of the 375 hours. The fading of the blue voile was more extensive than the fading of any other fabric.

Green Fabrics. The colors of the green Pamico, zephyr, and voile were approximately the same except for value or brilliance, the voile being lighter than the other two. From the curves in Figures 16, 17, and 18 it is noted that the zephyr showed less fading than the Pamico and much less than the voile. Both the zephyr and the Pamico changed throughout the entire length of the spectrum, the greatest change being toward the red end of the spectrum. Borho (9) found that the fastness of Anthrene Jade Green, the dye used in the green Pamico, decreases rapidly in light shades. Had higher concentration of dye been used the Green Pamico probably would have faded less. The voile began fading at an earlier hour and suffered greater total color change than did the Pamico or zephyr. The greatest change occurred in the red portion of the spectrum. Like the blue voile, there was preceptible change after one day's exposure. After 375 hours the fabric was a dingy, grayed yellow color, with none of the original green apparent. Of these three the zephyr was most fast and the voile least fast in color.

Yellow Fabrics. The chroma, strength or intensity, of the yellow of the Pamico cloth was greater than that of the yellow zephyr or voile as is shown by a comparison of the spectrophotometric curves in Figures 19, 20, and 21. The zephyr underwent the least change in color but after 275 hours there was a noticeable graying from the original color. The Pamico shows the same type of change but to a greater degree. The "fading darker", which is particularly noticeable in the Pamico, is a color change characteristic of certain yellow dyes. It is noted that in all color curves for the yellow fabrics, there is a crossing of the curves with the higher end becoming lower and the lower end higher. This change results in a straighter line with the chroma decreased and a more grayed color. This turning and straightening of the curve is a characteristic change occurring in many dyes. It is noted that the curves do not converge at the same wave length for the three yellows but that the voile crosses at a higher point due to the comparatively higher percentage reflection at the

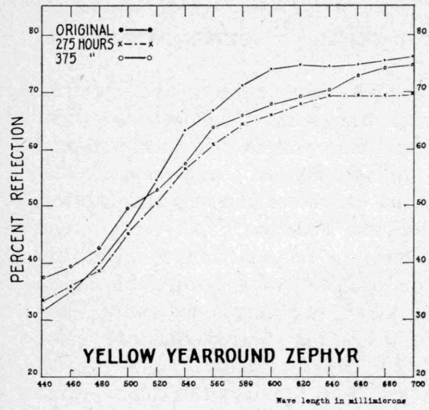


Fig. 19. Color curves for unexposed and exposed yellow Yearround zephyr.

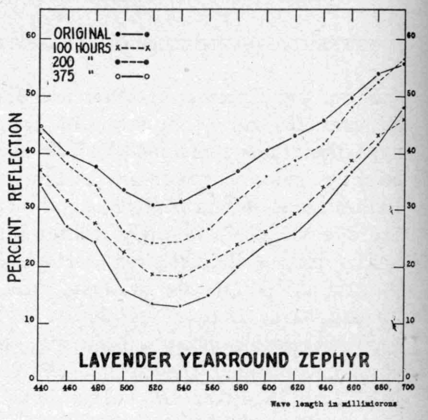


Fig. 22. Color curves for unexposed and exposed lavender Yearround zephyr.

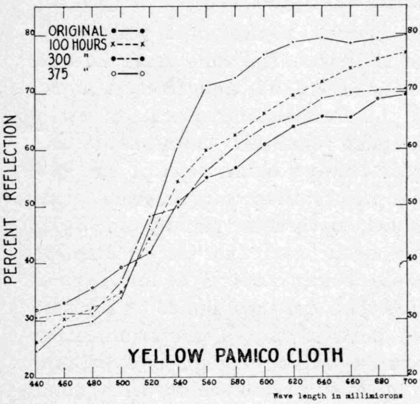


Fig. 20. Color curves for unexposed and exposed yellow Pamico cloth.

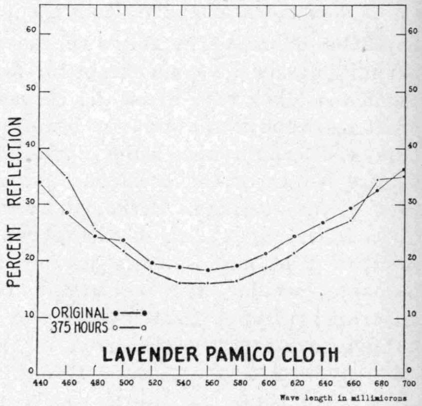


Fig. 23. Color curves for unexposed and exposed lavender Pamico cloth.

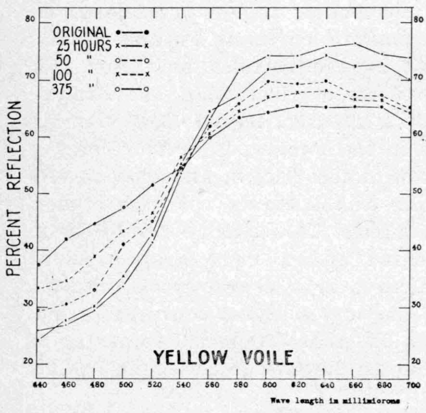


Fig. 21. Color curves for unexposed and exposed Pamico cloth.

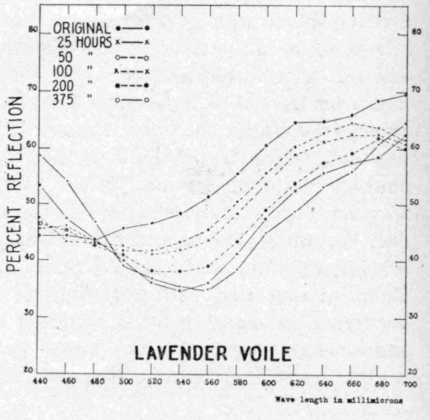


Fig. 24. Color curves for unexposed and exposed lavender voile.

longer wave lengths. Among the three yellow fabrics, the voile showed the greatest color change and the zephyr the least. The yellow voile faded less than the blue voile. These two colors had one dye in common, the Erie Yellow Y, used alone for the yellow and in combination with Niagara Blue 6B in the blue. This difference in fading suggests that the blue dye was less fast than the yellow or that the combination produced greater fading than did the yellow alone.

Lavender Fabrics. The brilliance and chroma of the lavender Pamico and zephyr were very similar, as the curves in Figures 22, 23, and 24 indicate. The Pamico showed very little change in color after 375 hours. At the end of that period the brilliance, or value, was slightly less, the fabric appeared lighter and of slightly weaker chroma. The zephyr faded somewhat more and to approximately the same extent as the lavender voile. The zephyr became lighter throughout the entire spectrum while the Pamico and voile showed lower percentage reflection at the violet portion of the spectrum. These changes resulted in a zephyr of practically the same hue but of less brilliance than the unexposed fabric, a lavender voile less brilliant and of weaker chroma than before exposure and a lavender Pamico in which there was little perceptible change between the original and exposed fabric.

Pink Fabrics. The differences in hue of the pink zephyr, Pamico, and voile are very noticeable in the spectrophotometric curves in Figures 25, 26, and 27. It is seen from the curve for the voile that this is a very strong color, which the dyer aptly named "flame". There is less difference in the hue of the zephyr and Pamico. The Pamico showed comparatively little change in color after 375 hours of exposure but at that time was a less strong and more grayed pink. The zephyr became much more grayed than the Pamico, as is indicated by the straightening of the curve. It is noted in the zephyr and voile that the least color change occurred at the red end of the spectrum, the portion reflecting the preponderence of light. The pink voile underwent the least change in color of all voiles. It was the only colored voile in which the original color could be detected with the eye alone after 375 hours of exposure. The Pamico was the least faded of the three pink fabrics. A partial explanation of the greater fastness of the pink voile over the other voiles may be its much stronger chroma. There was more color in the pink originally than in any of the other voiles. The

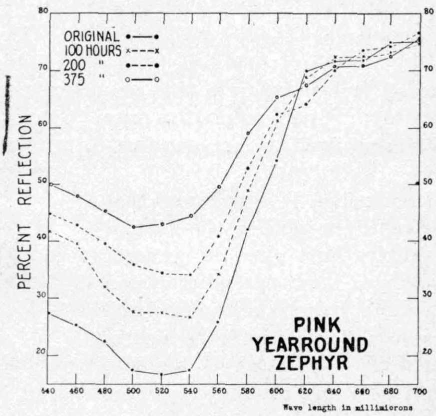


Fig. 25. Color curves for unexposed and exposed pink Yearround zephyr.

voiles, with the exception of the yellow, were lighter in brilliance than either the zephyrs or Pamicos. This may be one explanation of the apparent greater fading of the voiles in general. According to Barker (6) different concentrations of the same dye undergo the same total loss in color but the darker colors lose a lower proportion of the original color, which causes them to appear to fade less than the lighter shades. This would be true of color changes apparent to the eye but not so true of spectrophotometric measurements where actual and not apparent changes are measured. The fading of the dyes was undoubtedly due to the use of dyes by nature less fast than those used in the other fabrics, or to improper application or after treatment (10). Each of these voiles, except yellow, was dyed with a combination of two direct dyes, as given in Table 16. What the effect of each of these dyes alone would have been is not known. It is possible that the combination caused greater fading in some cases. It is known that blue, gray, and purple direct dyes are particularly sensitive to the actinic action of sunlight (46). The positive test for sulphate given by all colored voiles suggests that an after treament of salt containing sulphate, possibly copper sulphate, may have been used to increase fastness (10).

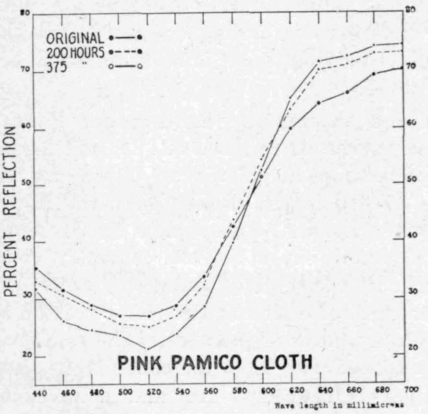


Fig. 26. Color curves for unexposed and exposed pink Pamico cloth.

Conclusion. It was found that the vat dyes used in the fabrics of this study were in general much more fast to sunlight than the direct dyes. The zephyrs and Pamicos were equally divided in fastness—the blues of the two fabrics being equally fast, the green and yellow zephyrs less faded than the Pamicos of the same color, and the lavender and pink Pamicos less faded than the same colors in the zephyr. The bleached muslins became slightly lighter, and then gradu-

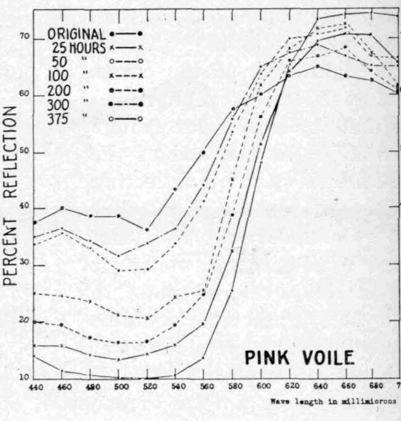


Fig. 27. Color curves for unexposed and exposed pink voile.

ally darkened becoming more yellow. The unbleached muslins became lighter. The white mercerized fabrics showed darkening and yellowing after exposure.

Contrary to popular opinion, no one color can be said to be more fast than other colors. Fastness is dependent upon the nature of the individual dye and not its hue.

Price was no indication of fastness. The voiles, least fast of the three types of fabrics, were most expensive. The guaranteed Pamicos and zephyrs were more fast than the non-guaranteed voiles.

Colors Classified by Direct Observation

The sub-committee on light fastness of the American Association of Textile Chemists and Colorists has chosen a comparatively rapid subjective method of classifying fabrics as to color fastness using seven classes as follows: (15)

Class 0. Dyeings which show an appreciable alteration in color when exposed for 6 hours in the standard sun test[1] and considerable alteration when exposed for 12 hours.

Class 1. Dyeings which show little or no alteration in color when exposed for 6 hours, but which show an appreciable alteration in 12 hours.

Class 2. Dyeings which show little or no alteration in color when exposed for 12 hours, but appreciable alteration in 24 hours.

Class 3. Dyeings which show little or no alteration in color when exposed for 24 hours, but appreciable alteration in 48 hours.

Class 4. Dyeings which show little or no alteration in color when exposed for 48 hours, but appreciable alteration in 96 hours.

Class 5. Dyeings which show little or no alteration in color when exposed for 96 hours, but appreciable alteration in 192 hours.

Class 6. Dyeings which show little or no alteration in color when exposed for 192 hours.

Dyeings were selected from among their tested samples to serve as standards for each class and other dyeings compared with these standards.

An attempt was made to classify the fabrics of this study using the same classification. Six people at College Station working independently and using the same specimens, made the classifications. Because of wide differences in the first classification, the fabrics were classified a second time without reference to the former classification. In nearly half of the cases, 10 of the 22, the second classification varied from the first. Individuals vary in their conceptions of what constitutes preceptible and appreciable color changes. These comparisons emphasize the greater reliability of objective over subjective methods of determining color. An average of these two classifications for the six people gives the results listed in Table 17.

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[1]Exposed on clear days between 9 a.m. and 3 p.m. under window glass at an angle of 45° from the horizontal, facing South, and with ½ inch between glass and fabric.

When these classifications are compared with the spectrophotometric curves several discrepancies appear. For example, the yellow and lavender voiles show approximately equal color changes early in the exposure period but are classified differently. The same is true of the Hope and the Lonsdale

Table 17. Dyeings classified by direct observation according to classification of sub-committee of A. A. T. C. C.

Fabric	White	Blue	Green	Yellow	Lavender	Pink
Yearround Zephyr	5	4	3	3	3	2
Pamico Cloth	3	5	3	3	4	3
Voiles	4	1	1	2	1	1
Muslins:						
Hope	3					
Lonsdale	2					
Lockwood	6					
Puget Sound	6					

muslins and of the blue and lavender Pamico suitings. Many of these fabrics suffered most of their color loss early in the exposure period with little additional loss as the exposure increased and only this first color change is considered in this classification.

Five of the dyes used in the dyeings classified by the sub-committee were used in the dyeing of the fabrics included in the present study but comparisons cannot be made on account of the differences in concentrations and combinations of dyes.

Comparison of Atmospheric Conditions. Atmospheric conditions are known to influence the color of cotton fabrics when exposed to sunlight. Therefore the atmospheric conditions under which the exposures were made at College Station were compared with the Washington atmospheric conditions under which the sub-committee made the exposures which were used in determining the classes. The temperature and relative humidity for the uncovered specimens exposed for a period of 384 hours at Washington were chosen as the nearest duplication of the conditions of the 375 hours of exposure made in Texas (16).

The months included at Washington in the exposure of the 1926 dyeings were June to October in 1926, and June to September in 1927. The average temperature and relative humidity for the hours 9, 12, and 3 were 32°C. and 45.5% respectively. In the exposures of the 1927 dyeings June to October in 1927, and March and April, 1928 were included. The average temperature and relative humidity taken at the same hours for the second 284 hours of exposure were 26.0°C. and 42.0% respectively. The Texas exposures were for 2 days in May and from June to October, 1929 and 13 days in July, 1930. The average temperature and relative humidity for this 375-hour period taken at the same hours—9, 12, and 3—were 31.0°C. and 48.36% respectively.

Comparing these exposure periods we find that during the first 384-hour period in Washington the temperature was 1°C higher and the relative humidity approximately 3% lower than for the 375 hours in Texas. The averages for the second 384-hour period in Washington were 5°C. lower in temperature and 6.4% lower in relative humidity. If the average of the two periods is compared with that of Texas we have 29°C. and 43.75% relative humidity for Washington and 31°C. and 48.36% for Texas. In all cases the relative humidity in Texas exceeded that in Washington by 3 to 6%. If such slight differences in temperature and relative humidity affect fading, the color changes due to their influence should be slightly greater in Texas than in Washington.

Conclusions. It is concluded from this color study that all fabrics, whether white or colored, undergo some color change during exposure to sunlight. It is evident that there is no absolutely fast color although dyes of satisfactory fastness may be secured in any desired color. No one color is necessarily more fast than another, but fastness is dependent on the nature of the individual dye and not its hue. In general, dark colors are more fast to light than light colors. Unbleached fabrics become whiter upon exposure while bleached undyed fabrics become more yellow. Not all dyed fabrics react in the same manner. Some become lighter, as did the green Pamico, while others become darker, as shown in the curve for the yellow Pamico. Some colors become lighter and then darker as did the Lonsdale muslin, while others darken and then become lighter, as in the case of the yellow zephyr. Others darken only, as did the white voile. Some colors change in hue, as illustrated by the blue and green voiles. Neither is the rate of fading the same for all dyeings. Some fade rapidly at first and then more slowly; others show rapid fading early in the exposure period, followed by a decrease in the rate of fading. Exposure decreases the luster of mercerized fabrics.

It is concluded that of the dyes included in this study, the vat dyes used in the Pamicos and zephyrs were more fast to sunlight than the direct dyes used in the voiles. The non-guaranteed voiles were more expensive and the dyes more fugitive than the less expensive guaranteed zephyrs and Pamicos.

ACKNOWLEDGMENT

The author is indebted to Julia Southard, temporary staff member, for material assistance in the determination of sizes, finishes, copper numbers, and ultra-violet radiation of the sunlight. Thanks are due to T. R. Hamilton, Associate Professor of Accounting and Statistics, for helpful suggestions concerning the correlation analyses.

SUMMARY

Twenty-two cotton fabrics, some white and some colored, consisting of Hope, Lonsdale, Lockwood, and Puget Sound muslins, Yearround zephyr, Pamico suiting, and Resilio voiles, were exposed to sunlight 25 to

375 hours in 25-hour periods. In all cases, there was a change in breaking strength and a change in color. The loss in strength was not at the same rate or to the same extent in all fabrics. The average loss in the breaking strength of the fabrics after 375 hours of exposure ranged from approximately 8 to 47 per cent in the warp and from 18 to 58 per cent in the filling.

The zephyr ginghams and Pamico suitings which were dyed with vat dyes, lost less strength, with the exception of the yellow zephyr, than did the voiles which were dyed with direct dyes. The yellow zephyr was evidently dyed with one of the yellow vat dyes known to cause a loss in strength. Dark colors were in general less weakened than light colors, probably due to the increased protection given by the vat dyes when in higher concentration and to greater resistance to the penetration of the light waves which produce tendering.

Coarse, hard twisted yarns were in general less tendered than fine, soft twisted yarns. Mercerized fabrics were less tendered than unmercerized and unbleached less than bleached fabrics.

By the use of correlation analysis it was found that of the environmental factors, hours of exposure had much the greatest effect upon loss in strength with temperature next, accounting for nearly twice as much of the change as did relative humidity. The same type of analysis showed that of the structural factors, only the percentage take-up and the ply had significant effects upon the change in strength. The environmental factors caused much more of the change in strength than did the structure of the yarns and fabrics.

A comparison of the sizes and finishes with the loss in strength of each fabric suggested that some of the added substances had a tendering effect.

From comparisons of the random, the random Latin square, and the systematic random method of sampling it was concluded that the systematic random method used in this study, in which a sample was composed of nine specimens, gave sufficiently accurate results.

The effects of the various periods of exposure upon the formation of oxycellulose were determined by the use of copper numbers. It was found that in general an increase in hours of exposure resulted in a higher copper number but the increase in copper number was not constant, probably because of the successive chemical reactions occurring in the formation of oxycellulose.

Spectrophotometric analysis of the color of each fabric before and after exposure to sunlight showed that all fabrics, whether white or dyed, underwent some change in color. Unbleached fabrics became lighter and bleached undyed fabrics became grayer and more yellow. The dyed fabrics varied in the type and extent of color change. Some became lighter, some darker, some darker and then lighter; others changed in hue. No one color can be said to be more fast than other colors but the fastness varies with the fastness of the individual dye when used alone or in combination with other dyes. Fabrics dyed with vat dyes, the zephyrs and Pamico suitings, were more fast than the voiles dyed with direct dyes. Dark colors appear to fade less than light colors. The guaranteed fabrics, zephyrs and Pamico suitings, were less faded than the non-guaranteed voiles. Price was no measure of fastness or retention of strength.

Classifying fadings by direct observation and giving each fabric a class number was found unsatisfactory. It was concluded that when at all possible, objective measurements of colors should be made.

Comparison of the ultra-violet radiation of the sunlight at College Station with other regions shows College Station to have approximately one-third greater ultra-violet radiation than Chicago, somewhat more than San Juan, P. R., and approximately three times as much as Honolulu. The sunlight at College Station therefore probably causes more tendering of fabrics and greater fading of certain dyes than does the sunlight at Chicago, San Juan, or Honolulu.

The results obtained in this study emphasize the importance of avoiding unnecessary exposure of cotton fabrics to sunlight, particularly in this section of Texas or in other regions where the ultra-violet radiation of the sunlight is great.

From this study it is concluded that to lose the least strength upon *exposure to sunlight, a cotton fabric should be composed* of unbleached, mercerized, coarse, hard twisted yarns. If dyed, a vat dye with protective characteristics and in a high concentration should be used. In purchasing cotton fabrics which will be exposed to sunlight, the consumer should consider not only price per square yard, but also the guarantee. The fastness of the dye is not dependent upon the color. Fast dyes may be secured in any color if there is wise selection in the choice of the individual dye or in the combination of dyes.

LITERATURE CITED

1. Anderson, Wm. T., Jr. 1928. The light that fades. Am. Dyestuff Reptr., 17:753.
2. Anderson, Wm. T., Jr., Robinson, F. W. 1925. The oxalic acid-uranyl sulphate ultra-violet radiometer. J. Am. Chem., Soc. 47:718.
3. Appel, Wm. D. 1928. Progress in the standardization of tests for fastness to light. Am. Dyestuff Reptr., 17:755.
4. Appel, Wm. D., Smith, Wm. C. 1928. Report of the sub-committee on light fastness. Am. Dyestuff Reptr. 17:410.
5. Bancroft, W. D. 1929. The colloid theory of dyeing. Am. Dyestuff Reptr., 18:148.
6. Barker, S. G. 1927. The standardization of the fastness of dyestuffs. J. Text. Inst., 18:T313.
7. Barr, G., Hadfield, I. H. 1927. The nature of the action of sunlight on cotton. J. Text. Inst., 18:T490.
8. Birtwell, C., Clibbens, D. A., Geake, A., Ridge, B. P. 1930. The chemical analysis of cotton. J. Text. Inst., 21:T85.
9. Borho, Ernest. 1930. Light fastness of Anthrene Jade Green and vat yellows. Text. World, 77:3650.

10. Borho, Ernest. 1929. The effect of textile softening materials on the Fade-Ometer fastness of direct dyes. Am. Dyestuff Reptr., 18:699.
11. Brugmann, E. W., Turner, L. B., Phillips, J. B. 1931. Action of sunlight on cotton. Text. World, 79:1553.
12. Bureau of Standards. 1926. U. S. government general specifications for textile materials. Federal Specifications Board specification. No. 345 and 345a.
13. Byam, S. C. 1928. Manufacture of rubberized cloth and attendant dyed cloth problems. Text. World, 74:3237.
14. Cady, Wm. H. 1931. Peculiarities of fading. Am. Dyestuff Reptr., 20:232.
15. Cady, Wm. H., Smith, Wm. C., Appel, Wm. D. 1931. Classification of the fastness of dyed textiles in the standard sunlight exposure test. Am. Dyestuff Reptr., 20:359.
16. Cady, Wm. H., Appel, Wm. D. 1929. Report of the sub-committee on light fastness. Am. Dyestuff Reptr., 18:407.
17. Committee D-13 on textile materials. 1930. A. S. T. M. Specification and methods of test for textile materials.
18. Cunliffe, P. W. 1932. Fastness of colored materials to light. Text. Rec. No. 588, 49:62.
19. Cunliffe, P. W., Farrow, F. D. 1928. The loss of strength of cotton exposed to light. J. Text. Inst., 19:T169.
20. Davidson, George F. 1932. The oxidation by gaseous oxygen of cotton impregnated with sodium hydroxide solution. J. Text. Inst., 23:T95.
21. Dorrough, Ada Bell. 1931. A chemical determination of the amount of ultra-violet light in the sunshine of Denton, Texas. Thesis submitted at Texas State College for Women, Denton, Texas.
22. Godfrey, Lois Stewart. 1931. The ultra-violet in solar radiation. J. Prev. Med., 5:1.
23. Hall, A. J. 1930. The copper number of cellulose. Am. Dyestuff Reptr., 19:355.
24. Haller, R., Ziersch, G. 1929. Photochemical decomposition of simple azo-dyestuffs. Mell. Textilber, 10:951. Abs. Am. Dyestuff Reptr., 19:503, 1930.
25. Hernandez, Luis G., McKinley, Earl B. 1931. Ultra-violet light intensity of the sun in Porto Rico, P. R. J. of Pub. Health and Trop. Med., 6:401.
26. Hess, Katharine. 1932. Modified serigraph method. Text. World, 81:25.
27. Jameson, C. W. 1932. Foretelling color fastness with an artificial sun. Am. Dyestuff Reptr., 21:306.
28. Kauffman, H. 1931. Cotton tendering catalysts: activity. Z. angew. Chem., 44:490. Abs. J. Text. Inst., 22:A503.
29. Kauffman, H. 1931. Iron: catalytic action in tendering. Z. angew, Chem., 44:858. Abs. J. Text. Inst., 23:A32.
30. Keuffel and Esser Company. Directions for the care and use of Keuffel and Esser color analyzer.

31. Landolt, A. 1929. Behavior of vat dyeings on cotton under exposure to light. Am. Dyestuff Reptr., 18:813.
32. Landolt, A. 1929. Vat-dyed cotton: tendering by light. J. Text. Inst., 20:A554.
33. Landolt, A. 1930. Vat-dyed cotton: effect of light. Textilber, 11:937. Abs. J. Text. Inst., 22:A250.
34. Landolt, A. 1931. The tendering of dyed fabrics on exposure to light. J. Text. Inst., 22:A41.
35. Larsen, Nils P., Godfrey, Lois Stewart. 1931. The ultra-violet in solar radiation. J. Prev. Med., 5:25.
36. Matthews, J. Merritt. 1920. Application of dyestuffs. John Wiley and Sons.
37. Scharwin, W., Packschwer, A. 1930. Dyed cotton and linen: fading. Trans. Sci. Res. Inst. Text. Ind., U. S. S. R., 1:15. Abs. J. Text. Inst., 22:A150
38 Schoffstall, Chas. W., Hamm, H. A. 1929. A multiple-strand test for yarns. Bureau Stand. J. of Research, 2:871.
39. Scholefield, F., Goodyear, E. H. 1929. Action of light upon cotton dyed with certain vat-dyestuffs. Mell. Textilber, 10:867. Abs. Am. Dyestuff Reptr., 19:506.
40. Scholefield, F., Patel, C. K. 1928. Vat-dyed cotton: tendering by light. J. Soc. Dyers. and Col., 44:268. Abs. J. Text. Inst., 20:A205.
41. Schorger, A. W. 1926. The chemistry of cellulose and wood. p. 275. McGraw-Hill Book Company.
42. Smith, G. 1931. The chemical analysis of sized cloth. Am. Dyestuff Reptr., 20:118.
43. Smolens, H. C. 1928. Hydrogen peroxide bleach. Text. World, 74:3237.
44. Sub-committee of Am. Assoc. Text. Chem. and Col. 1931. Identification of sizing and finishing materials. Am. Dyestuff Reptr., 20:690.
45. Technical editor. 1929. Yellow stain on cotton. Text. World, 76:4246.
46. Technical editor. 1931. Half hose are faded. Text. World, 79:2395.
47. Technical editor. 1929. Tendering of black braid. Text. World, 76:3065.
48. Tippett, L. H. C. 1930. Statistical methods in textile research. J. Text. Inst., 21:T105.
49. Tonney, F. O., Somers, P. P., and Marti, Wm. C. 1928. Actinic measurement of solar ultra-violet light and some correlations with the erythema dose. J. Prev. Med., 2:493.
50. Turner, A. J. 1931. Random and systematic selections of warp specimens in cloth sampling. J. Text. Inst., 22:T77.
51. Turner, A. J. 1928. The relation between atmospheric humidity and the breaking strengths and extensibilities of textile fabrics before and after weathering. J. Text. Inst., 19:T101.
52. Westford, L. C. 1931. Recent investigations shed new light on effect of moisture on cotton strength. Text. World, 80:2088.
53. Wilkie, J. B. 1931. Laundered cotton goods: winter damage—causes and prevention. Bureau Stand. J. of Research, 6:593.

54. Wuth, B. 1929. Optical heterogeneity and its influence on the fastness to light of vat dyeings. Am. Dyestuff Reptr., 18:117.

55. Zierhold, F. 1928. Cotton: action of ultra-violet light. Dissertation Techn. Horschule Dresden. :71. Abs. J. Text. Inst., 1929. 20:A201.

56. ——— 1927. Action of light on cotton. Mell. Textilber, 7:617. Abs. Am. Dyestuff Reptr., 16:41.

57. ——— 1928. Effect of sun's rays. Text. World, 74:1677.